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Demonstration of Standard HVAC Single-Loop Digital Control Systems

by
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U.S. Army Engineering and Housing Support Center
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Innovative Ideas for the Operation, Maintenance, & Repair of Army Facilities

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The U.S. Army Corps of Engineers' Guide Specifications (CEGS) 15950 and Technical Manual (TM) 5-815-3 on heating ventilating and air conditioning (HVAC) control systems provide guidance on designing and specifying standard HVAC control systems that use single-loop digital controllers. This study demonstrated the retrofit of standard control systems to HVAC systems to evaluate standard HVAC control system equipment and designs, and to evaluate the CEGS and TM documents.

Standard HVAC control systems were retrofitted at two Army installations. At the first site, researchers constructed, installed, and commissioned a prototype of the standard HVAC control system. At the second site, researchers provided technical assistance to the Directorate of Engineering and Housing (DEH) engineer, who designed a standard HVAC Control System and hired a local contractor to construct, install, and commission the system.

Results showed that the standard HVAC control systems could be installed in the field and correctly control HVAC systems. Since installation, these control systems have accurately controlled the HVAC processes and proven to be reliable, low-maintenance systems. Recommendations were made for improvements to the CEGS and TM 5-815-3 to help simplify and improve the process of specifying, installing, and maintaining standard HVAC control systems.

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FOREWORD

This study was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC), Fort Belvoir, VA, under the Facilities Engineering Applications Program (FEAP); Work Unit EB-FQ, "Evaluation of Single Loop Digital Control Panels." The USAEHSC technical monitor was Mr. Christopher Irby, CEHSC-FU-M.

This research was performed by the Energy and Utility Systems Division (FE), of the Infrastructure Laboratory (FL), of the U.S. Army Construction Engineering Research Laboratories (USACERL). Glen A. Chamberlin was the USACERL principal investigator and Victor L. Storm was the Engineering Technician. Dale L. Herron is the Team Leader of the Energy Conservation Team (CECER-FEC). Dr. David M. Joncich is Division Chief, CECER-FE, and Dr. Michael J. O'Connor is Laboratory Chief, CECER-FL. Appreciation is extended to the many personnel at Fort Leonard Wood, MO and Fort Campbell, KY who assisted on this project. The USACERL technical editor was William J. Wolfe, Information Management Office.

COL Daniel Waldo, Jr., is Commander and Director of USACERL and Dr. L.R. Shaffer is Technical Director.

CONTENTS

CONTENTS (Cont'd)

FIGURES

FIGURES (Cont'd)

FIGURES (Cont'd)

TABLES

DEMONSTRATION OF STANDARD HVAC SINGLE-LOOP DIGITAL CONTROL SYSTEMS

1 INTRODUCTION

Background

The U.S. Military has traditionally procured commercial-grade pneumatic controls for its heating, ventilating and air conditioning (HVAC) systems. The Government often preferred to buy such control systems because they had the lowest first cost, were easy to understand, and (to some degree) could be maintained by government technicians. Although by today's standards, pneumatic control systems could not control HVAC processes precisely, this seemingly small problem was offset by the simplicity of the systems, a general lack of concern for energy consumption, and the forgiving nature of the buildings, HVAC systems, and building occupants.

Over the years, standards have changed and energy efficiency has become a matter of policy. Several factors have combined to undermine the ability of these HVAC control systems to perform adequately. Many HVAC systems in the military have become energy wasters that cannot maintain comfortable building conditions. Lab work, field studies, and occupants' complaints all point to one conclusion: that the military must change its approach to controlling HVAC systems if it is to meet its energy usage goals and maintain building comfort.

Several organizations and individuals within the U.S. Army, Air Force, Navy, and private industry conducted research on HVAC systems and HVAC controls (Dolan 1982; Hittle et al. 1992; Chamberlin 1990). One conclusion of the research was that a need exists for guidance documents on the design of HVAC control systems. This research produced the first Corps of Engineers Guide Specification (CEGS) and Technical Manual (TM) for HVAC control systems. CEGS 15950 (U.S. Army Corps of Engineers [USACE] 1990) and TM 5-815-3 (U.S. Army Corps of Engineers [USACE] 1990) specify control system hardware and document control system designs based on concepts of standardization of control system designs and hardware, interchangeability of hardware, control accuracy, reliability, and diagnostic and maintenance features. In accordance with Corps of Engineers' general procedures, new products such as the control systems specified by CEGS 15950 and TM 5-815-3 must be formally field tested before they can be transferred to the field.

Objectives

The initial objectives of this project were to demonstrate and evaluate standard HVAC control system concepts, designs, and hardware, and to conduct technology transfer. This evaluation was to include issues of energy efficiency, control performance, reliability, and maintainability. Objectives that emerged during the project included evaluating CEGS 15950 and TM 5-815-3 for correctness, completeness, understandability, biddability, constructability, and overall ease of implementation. Other added objectives were: to refine commissioning procedures; to develop technician training requirements; and to develop procedures for performance verification, design review, and quality verification.

Approach

The field testing portion of the project was divided into two phases, conducted at two Army installations. The first phase of the project was conducted at Fort Leonard Wood, MO in the following steps:

1. The draft CEGS and TM were used to construct a prototype standard HVAC single-loop digital (SLD) control panel.

2. An installation site with typical HVAC configuration and controls was selected.

3. The prototype standard HVAC SLD control system was installed, commissioned, and performance verification tests were conducted.

4. A training course was conducted to help facility personnel learn to operate and maintain the standard HVAC control system.

5. Assistance was provided to the installation's maintenance personnel.

6. The performance and reliability of the standard control system was evaluated and monitored.

The second phase of the project was conducted at Fort Campbell, KY in the following sequence:

1. A building was selected for the demonstration.

2. A DEH designer was provided with design documents and some basic training on the standard controls, and then the designer was helped to assemble a contract package.

3. The contract package was reviewed, and assistance, as necessary, was provided to the designer and Fort contracting agent during bidding, submittal review, and construction review.

4. The contractor was assisted, as necessary.

5. Assistance was given to installation personnel during commissioning and acceptance.

6. The performance and reliability of the standard control system were monitored and evaluated.

Mode of Technology Transfer

Information from this project has been incorporated into CEGS 15950 and TM 5-815-3. Information has also been incorporated into four PROSPECT courses, conducted by the Corps of Engineers' Huntsville Division, Huntsville, AL: Course No. 340, *Design of Standard HVAC Control Systems*; Course No. 382, *Quality Verification of Standard HVAC Control Systems*; Course No. 327, *Commissioning of Mechanical Systems*; and Course No. 297, *EMCS—Operators*. Publications on the HVAC control systems described in this report include Facilities Engineering Application Program (FEAP) and U.S. Army Construction Engineering Research Laboratories (USACERL) fact sheets, and articles in the *DEH Digest* (Conrad-Katz, August 1989), the American Public Works Association *Reporter* (October 1989), and the *Technology Transfer Bulletin* (Conrad-Katz, 1989b). Presentations were done at the Corps of Engineers National Energy Team (CENET), HVAC Controls User Group, DEH World Wide, and Installation Engineers conferences.

2 DEVELOPMENT OF STANDARD HVAC SINGLE-LOOP CONTROL SYSTEMS

Background

Not only were the typical military-purchased HVAC control systems least first-cost, commercial-grade, pneumatic systems that lacked accuracy and required frequent maintenance, but the effort to design, contract, and approve was also low-cost. The military essentially lacked any specifications and design guidance for control systems so the contractor not only chose the equipment to be installed, but often set up the control strategy.

This approach appeared to work until several factors conspired to undermine this "easy going" attitude toward HVAC control systems. First, buildings and HVAC systems became more complicated, so the HVAC control systems also became more complicated. Factors such as air conditioning, humidity control, large interior spaces, and energy conservation all added complexity and control accuracy requirements to the HVAC systems. As the requirements caused the control systems to become more complicated, many new and often previously untried control strategies were used. Some of these control strategies malfunctioned, and many were so complex that they were hard to operate, maintain, and repair. This scenario often repeated itself within the large number of buildings typically located at an installation, resulting in a confusing variety of control systems that were difficult to keep operating correctly.

Field technicians in charge of many buildings found it increasingly difficult to keep up with the many different pieces of control hardware, and especially difficult to keep up with the many different control strategies. The knowledge base of the field technicians about the more complicated control systems fell behind the fast-changing industry. This inability to keep up with technology may have been due to several factors: a lack of appropriate training, a lack of emphasis on training, and a lack of desire. The efficiency of the technicians suffered due to a lack of knowledge at the same time the number of technicians per building decreased. In fact, this was a time when more complicated and maintenance-intensive systems required more (and better-trained) people.

Several other factors also came into play. Lower quality parts failed or went out of calibration quickly. Lower quality labor during installation and commissioning phases provided systems that did not work accurately or may not have even worked at all, and less stringent safety factors in designs reduced the needed margin for errors to a critical point. The end result was that the commercial-grade pneumatic control systems that the military was purchasing were not adequately keeping spaces comfortable and conserving energy.

HVAC Test Facility Research

Several programs studied and documented energy use and energy reduction in military facilities (Dolan 1982). These investigations showed that HVAC systems use much of the energy consumed in Army buildings. These studies of HVAC systems have indicated that some system configurations, such as variable air volume (VAV), single zone, and multizone systems, have better operating performance and consume less energy in particular applications than do others. Also, the studies found that the characteristics and operating condition of the control components for these systems can have significant effects on energy consumption.

USACERL became involved in HVAC controls research as a result of a project undertaken to study the energy efficiencies of various HVAC system configurations (Hittle and Johnson 1985). An HVAC Test Facility was constructed at USACERL to help study the energy performance of different HVAC

systems. From the start of the project, it became apparent that the pneumatic control system installed to control various air handling equipment did not perform as expected or required. While the system provided by the contractor was "state-of-the-art" at the time for commercial pneumatic control systems, repeated recalibration of the controls by USACERL researchers and the manufacturer revealed that the control components continued to perform below expected levels and would gradually drift out of calibration.

Standard military procedures had been used to procure the air handling equipment and controls for this project. At this time no specifications for control systems existed in contract documentation in the military. Mechanical contractors installing air handling equipment were required (or allowed) to design or subcontract control system design to controls specialists.

As the project progressed, researchers continued to investigate various types of commercial and industrial pneumatic control components in an effort to achieve the control performance required for their research. Information obtained from field engineers and maintenance staff confirmed that many Army HVAC control systems experienced problems similar to those demonstrated by the USACERL experimental setup.

Standardization Concepts

This study's investigation of the current design practices found that only general descriptions of the control functions were provided and that no performance requirements were stated in contracts. Complex and custom control strategies were often designed, which, when coupled with the low-cost control components, resulted in unsuccessful control strategies. The use of multiple input and output controllers resulted in the loss of more than one process when a controller failed. The systems were also found to lack good operation and maintenance instructions. Diagnostic equipment and devices, such items as display of inputs, outputs, and setpoints, were usually not provided with, or as part of, the system. Further research concluded that many commercial pneumatic controls for HVAC applications were inaccurate, unreliable, and maintenance-intensive—all factors that lead to energy-inefficient HVAC systems (Hittle 1982, Hittle and Johnson 1985). As a result, maintenance staffs would disconnect the controls or reconfigure them to perform only basic heating and cooling to decrease complaints, all at the expense of energy efficiency, comfort, and sometimes higher maintenance costs.

The concept was developed that, to improve control performance, the control system design should be simple, reliable, accurate, and maintainable. In addition, the control panel should incorporate diagnostic and display features to improve understanding of the system and maintenance. Specifically the military should adopt a few standard control strategies to simplify the information that maintenance personnel, contractors, and Government quality verification personnel need to understand. Control equipment should be interchangeable to increase market competition for these items and to reduce the need for a large, diverse inventory of spare parts.

Standard HVAC Analog-Electronic Control Systems

Based on the above concepts, USACERL researchers began to develop the standard HVAC control systems (Hittle and Johnson 1985, Chamberlin et al. 1990). Researchers tested and evaluated control equipment and began to develop control panels that incorporated analog-electronic controllers. These controllers incorporated proportional, integral, derivative (PID) control action, and were commonly used in industrial applications where they were known to be accurate and reliable. In addition to investigating

control hardware, common HVAC systems were identified, and simple, standard control sequences of operation were developed.

One such control concept was to break down the HVAC system into separate processes such as static pressure and supply air temperature control loops. Each process would then be controlled by a single controller, thus simplifying the control system. Control panels and system designs were standardized and finalized for the identified HVAC systems, and specifications were developed.

Several panels were constructed by controls manufacturers according to the designs and specifications. Figure 1 shows a standard HVAC analog electronic control panel. As part of the Facilities Engineering Application Program (FEAP), the panels were successfully installed at several Army facilities to validate the concept of installing factory assembled, prepackaged control panels. Operating data were gathered to analyze energy use and operating characteristics of the new controls, and a design guidance was published (Chamberlin et al. 1990).

In July 1986, the U.S. Air Force subsequently adopted these guidance documents, and required the use of the standard analog electronic control systems for use on new and retrofit construction projects through Engineering Technical Letter ETL-83-1 Change 1 (1986). The Army Corps of Engineers recommended the use of the standard analog electronic control systems but did not require them since a larger program aimed at the development of standardized HVAC controls had already been started.

Prototypes of Standard HVAC Single Loop Digital Control Systems

Development and improvement of the standardization concepts continued using lessons learned from the development of the standard analog control systems. An architect/engineering firm was contracted to study and develop a report (King-Linquist 1986) documenting the state of the art for HVAC controls. The report documented typical HVAC system configurations, control equipment, system schematics, and panel designs. Information from this report was combined with past knowledge to contribute to the evolution and continued development of the standard HVAC control systems. A larger effort was then undertaken to finalize the standard HVAC control system designs, and develop a Corps of Engineers Guide Specifications (CEGS) and a Technical Manual (TM) on HVAC control systems. The TM was to provide information to help engineers design HVAC control systems for the military. The TM would also include design drawings for the standard control systems. The CEGS would not only include specifications dealing with hardware, but also specifications dealing with documentation, commissioning, performance verification, and control sequences of operation. Eventually, 21 standard control systems were identified for HVAC systems typically used in the military (CEGS 15950 1990, TM 5-815-3 1990).

Development of control system designs, sequences of operations, and investigation of hardware continued on parallel paths during the development of the CEGS and TM. The hardware continued to center around the use of reliable, accurate equipment that was interchangeable from manufacturer to manufacturer. Resistance temperature detectors (RTDs) were specified for sensing temperatures and would be connected to transmitters that transmit 4 to 20 mA signals to the controllers. Other field process-sensing devices were specified and transmitters were specified so that all signals coming from transmitters were standardized at 4 to 20 mA. All control signals to devices were standardized at 4 to 20 mA signals, except for pneumatic actuation signals which were set at 3 to 15 psig.* This standardization of signals was designed to simplify diagnostic and troubleshooting-work. Single loop digital controllers (SLDC) replaced the analog electronic controllers because of their increased features, accuracy and reliability

*A metric conversion table is included on p 81.

VAV TEMPERATURE CONTROL PANEL

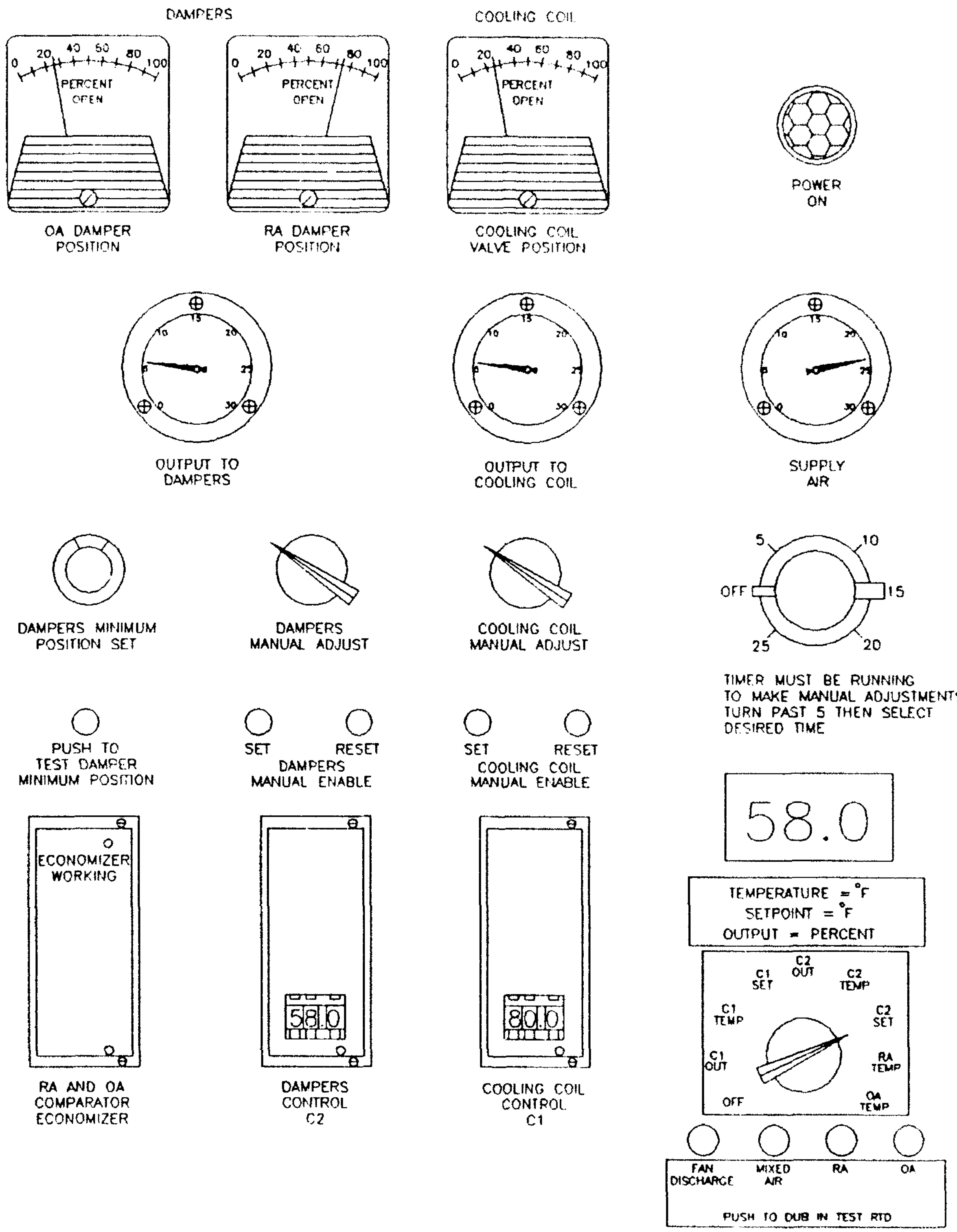


Figure 1. Standard HVAC Analog-Electronic Control Panel.

(Schwenk, Herron, and Alessi 1990). A control panel layout was developed, again incorporating standardized features. Panel-mounted devices were to be placed on a standard mounting rail to simplify replacement if they failed. Gages, pilot lights, and displays were to be incorporated into the panels to provide operational information and to help with troubleshooting.

During the spring of 1987, a control panel (Figures 2 and 3) was constructed by USACERL based on the latest draft designs and Guide Specification for HVAC control systems, dated 1 December 1986. In this version of the control panel, system condition pilot lights and switches were located at the top of the exterior panel door. Mounted in the inner door could be up to 10 controllers, a main air gage and current-to-pneumatic-transducer output gages. Standard device mounting rail (DIN rail) was installed on the back-plate of the panel and all other panel-mounted devices (relays, wiring terminals, function modules, system time clock, etc.) were rail mounted. The panel concept at this stage was to have standard locations for all panel-mounted devices that would be used in any of the identified standard HVAC control systems. For example, the controller for the supply air temperature control loop would always be located in the same place no matter which standard system was being used. If the standard system did not require a supply air temperature controller, then no controller was installed and a blank-off plate was installed in the space.

The purposes of building the first control panel were to determine if there were any problems with the acquisition of necessary components, to check the specifications, and determine the overall functionality of the design. Following the completion of the panel, several improvements were made to device descriptions and physical features of the panel, which led to the revision of the CEGS and TM. The revised CEGS and TM used two panels instead of just one, to accommodate the 21 standard control systems. A larger panel accommodated 10 controllers and a smaller panel would accommodate five.

In the fall of 1987, USACERL constructed a version of the larger control panel, incorporating six controllers into the design (Figures 4 and 5). This prototype version of the standard panel specified the use of a 48x36x16-in. Nation Electrical Mechanical Association (NEMA) 12 electrical enclosure with an inner door and a back plate for mounting devices and terminal strips.

In this version, the system operating-condition pilot lights and switches were located along the top of the inner door of the panel instead of on the exterior door. As before, the controllers were mounted in 3.62 x 3.62-in. openings in the inner door. Controllers from different manufacturers were intentionally installed to demonstrate their interchangeable design. As required, unused openings for controllers and gages were covered with blank-off plates. Also located on the inner door were air gages for I/P output indication, and a new design feature, electronic meters for position indication of damper and valve actuators.

The remaining panel devices were mounted on the back plate on the standard mounting rails. Plastic wiring troughs and an increased number of wiring terminals were incorporated into the new design. In this version, the top row contained the relays; the second row contained the system time clock and function modules; and the next four rows contained terminal strips for wire terminations of panel and field devices. The seventh row contained power supplies and conditioners, and the eighth row contained the current to pneumatic (I/P) transducers.

The panel was designed to control both a variable air volume with return fan system and a heat exchanger with outside air reset system. The control loops consisted of an economizer, mixed air temperature, discharge (supply) air temperature, supply duct static pressure, return fan volume, and hot water temperature.

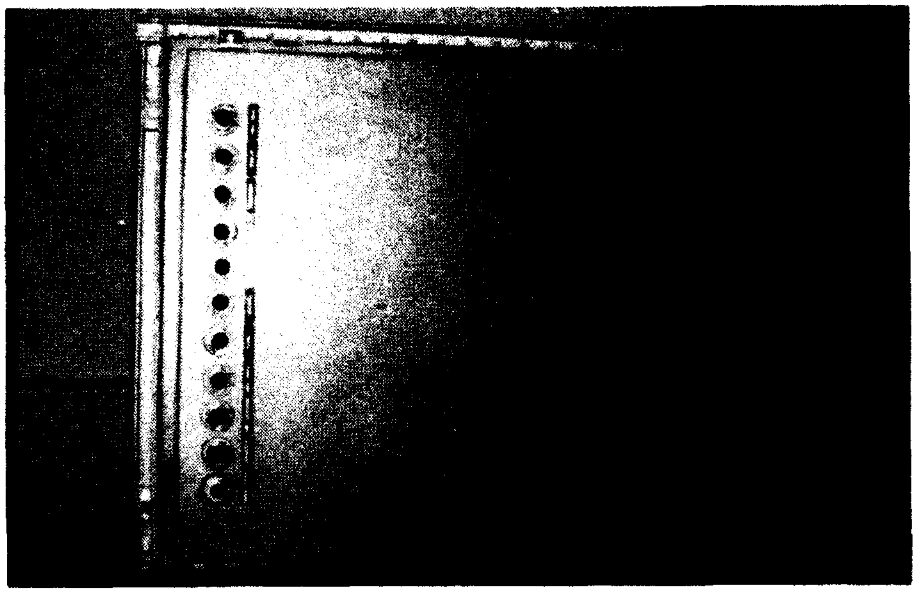


Figure 2. Early Prototype of Standard HVAC SLD Control Panel.

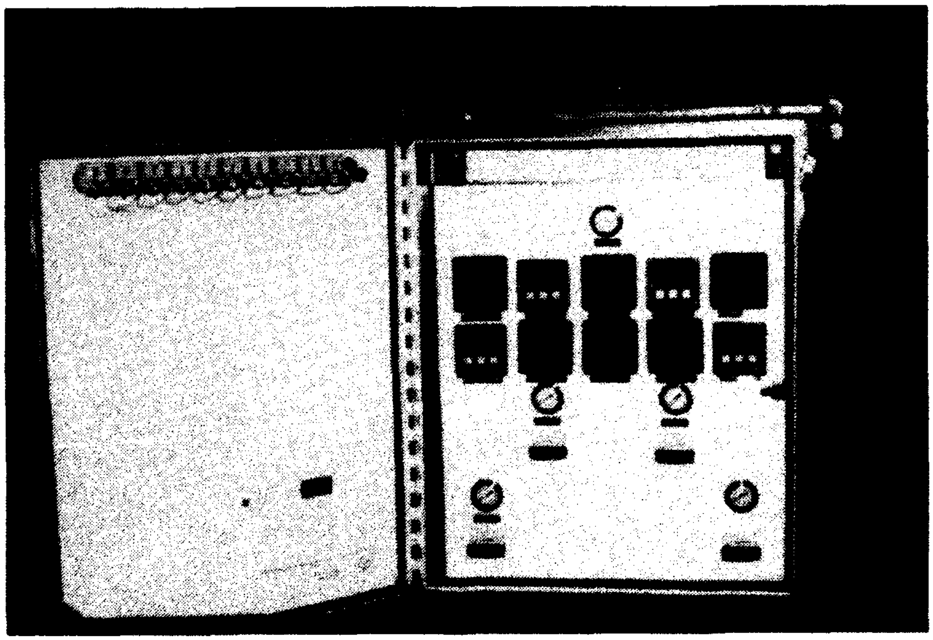


Figure 3. Early Prototype of Standard HVAC Control Panel—Inner Door.

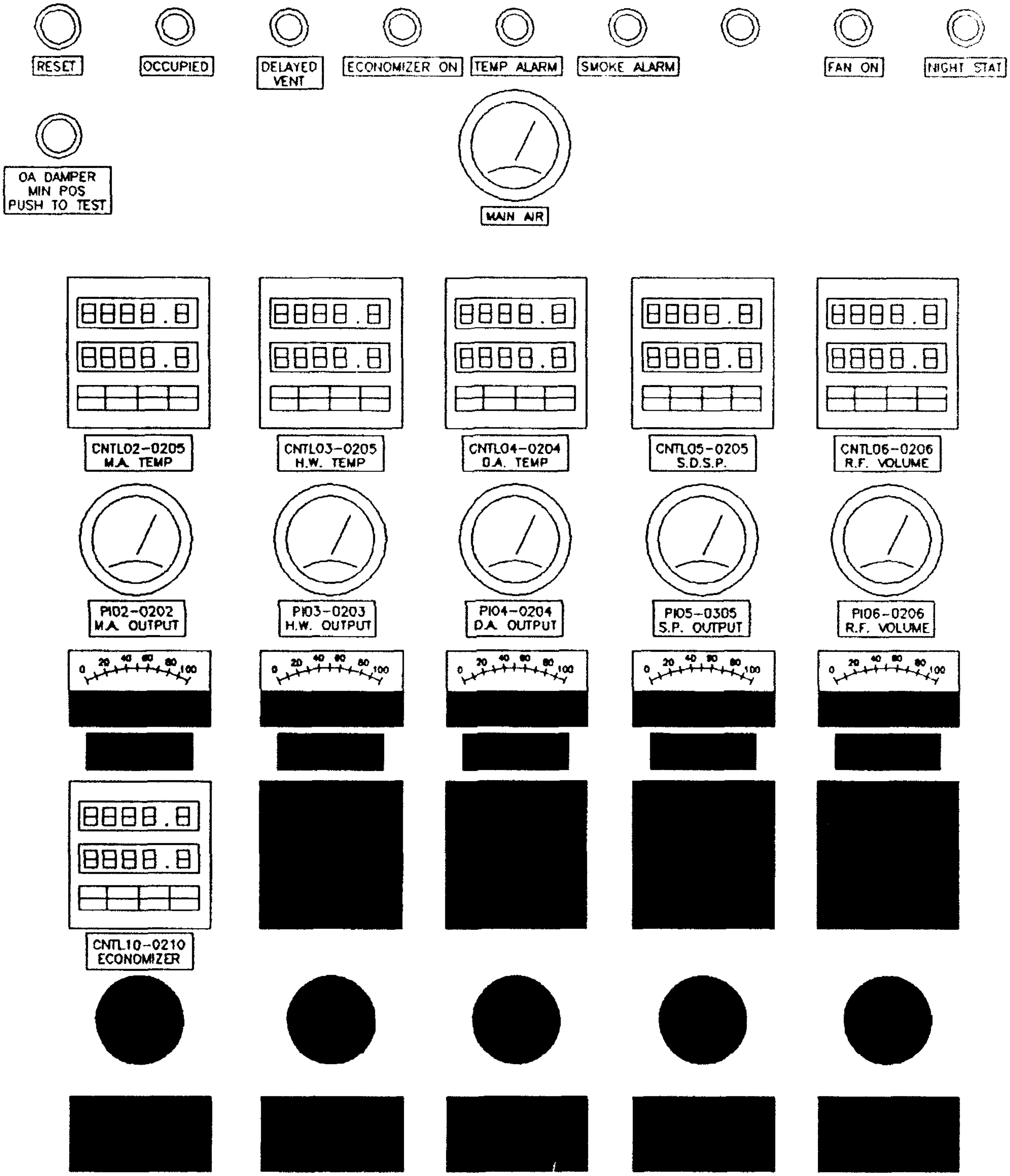


Figure 4. Schematic View of Prototype Standard HVAC Single Loop Digital Control Panel—Inner Door.

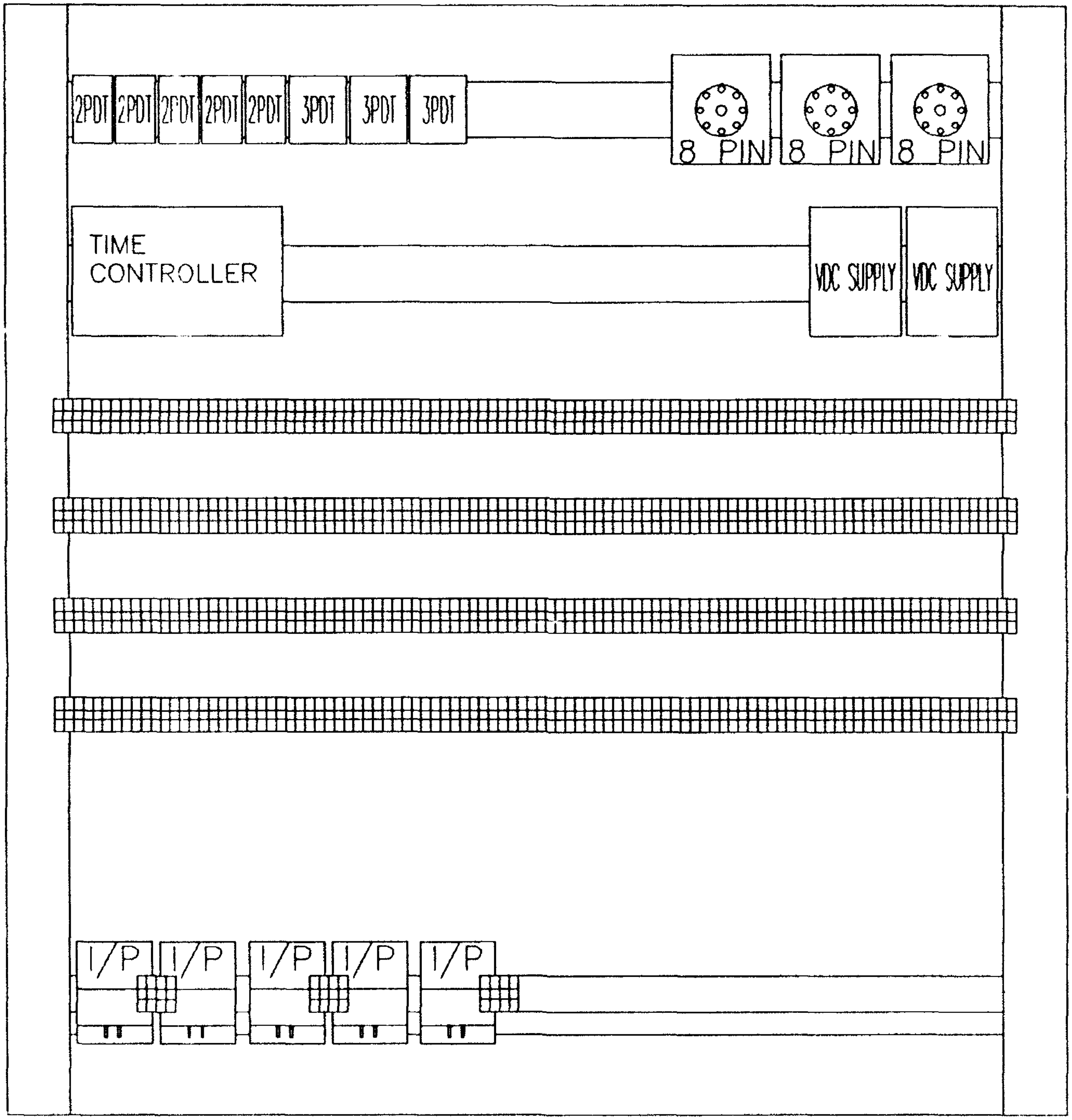


Figure 5. Schematic View of Prototype Standard HVAC Single Loop Digital Control Panel–Back Plate.

Features had been incorporated into the panel design to interface the control system with an energy monitoring and control system (EMCS). Functions such as air filter condition, fire/smoke alarm status, high static pressure alarm, low temperature alarm, controller inputs, etc., could be read by the EMCS.

Figure 6 shows the inner door of the control panel. After completion of the control panel, the next step was to install the control system in the field. Many concepts, designs, and interfacing considerations needed to be tested, and also the control system itself needed to be tested on an actual operating HVAC system.

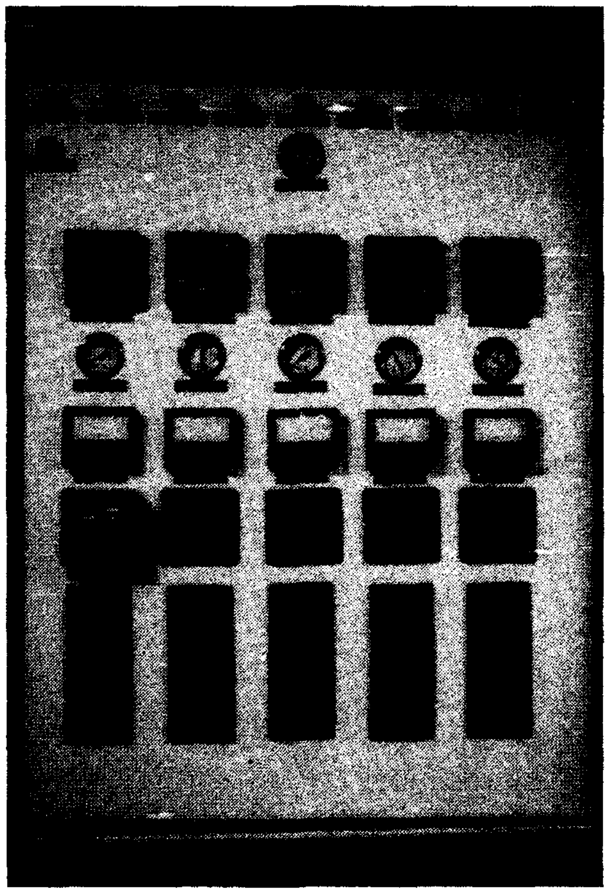


Figure 6. Panel To Be Installed at Fort Leonard Wood.

3 DEMONSTRATION AT FORT LEONARD WOOD, MO

Background

Building #5400 at Fort Leonard Wood, MO was selected for the first phase of the FEAP standard single loop digital HVAC control system demonstration project. USACERL chose the building since the HVAC system matched one of the standard HVAC control systems, because a good working relationship with the DEH personnel had developed during the FEAP sponsored electronic-analog control panel project, and because the site was only half a day's drive from the laboratories. The first phase of the project emphasized a field evaluation of the standard control system equipment, and an evaluation of the field connection between the control system and the building mechanical and electrical systems.

Overview

This phase of the project started in the fall of 1987 with the selection of the building and HVAC systems. Initial installation and commissioning of the new control systems were completed in the spring of 1988. Modifications to the control systems, testing of new control equipment and strategies were made, and final commissioning was completed in the spring of 1989. Training was conducted and the system performance was verified in June 1989. EMCS was connected to the standard control system in the summer of 1991. Several return visits have confirmed continued accurate control of the HVAC system and reliable operation of the standard control system.

Description of the Building and HVAC Systems

Building 5400, also known as Brown Hall, was a three-story, 114,000 sq ft building constructed in 1984 (Figures 7 and 8). The first floor of the building consisted of shop areas and administrative offices, and the second and third floors consisted of lecture rooms. The building was used for vertical skills training of soldiers (plumbing, carpentry, and electrical wiring).

Cooling and ventilation were supplied to the first floor administrative offices and to all of the second and third floors by two nearly identical VAV systems. Cooling and ventilation from the air handling unit were not provided to the shop areas, but several exhaust fans were located in the shop areas. Heating was supplied to all areas by various perimeter-fin- tube radiators, unit heaters, and constant-volume-with-reheat-terminal-units, which were supplied with hot water from a heat exchanger located in the building.

The VAV air handling units (AHUs) and heat exchanger (Figures 9, 10, and 11) were located in a mechanical room on the first floor. A high-temperature glycol solution for heating, and chilled water for cooling were supplied to the building from a central energy plant located at the Fort. AHU #2 and the heat exchanger were to be the objectives of the controls retrofit demonstration.

Air handling unit number one (AHU #1) was a typical/standard VAV with return fan system that provided cooling and ventilation to the administrative rooms on the first floor, and to the class rooms on the third floor. The constant-volume-with-reheat-terminal-units supplied heating to the hallways when required, and perimeter radiators provided heating in the rooms. AHU #1 had a maximum design air capacity of 14,350 cfm with a 55 °F air temperature setpoint for the supply air leaving the cooling coil.

AHU #2 was a typical/standard VAV with return fan system, which provided cooling and ventilation to the second floor and which was chosen for the demonstration. Figure 12 shows the system layout. Air

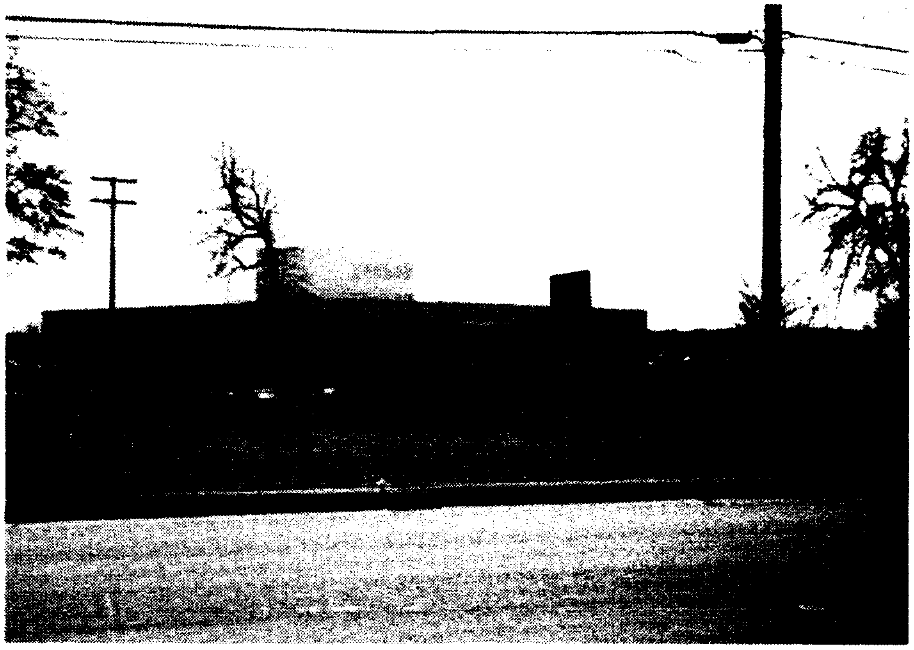


Figure 7. Brown Hall—North Side.

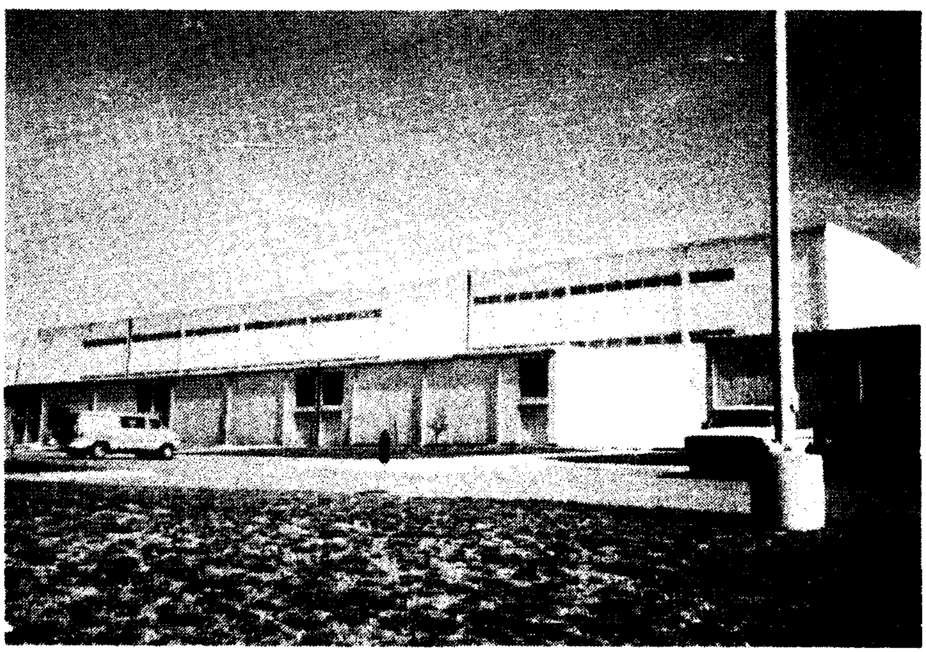


Figure 8. Brown Hall—East Side.

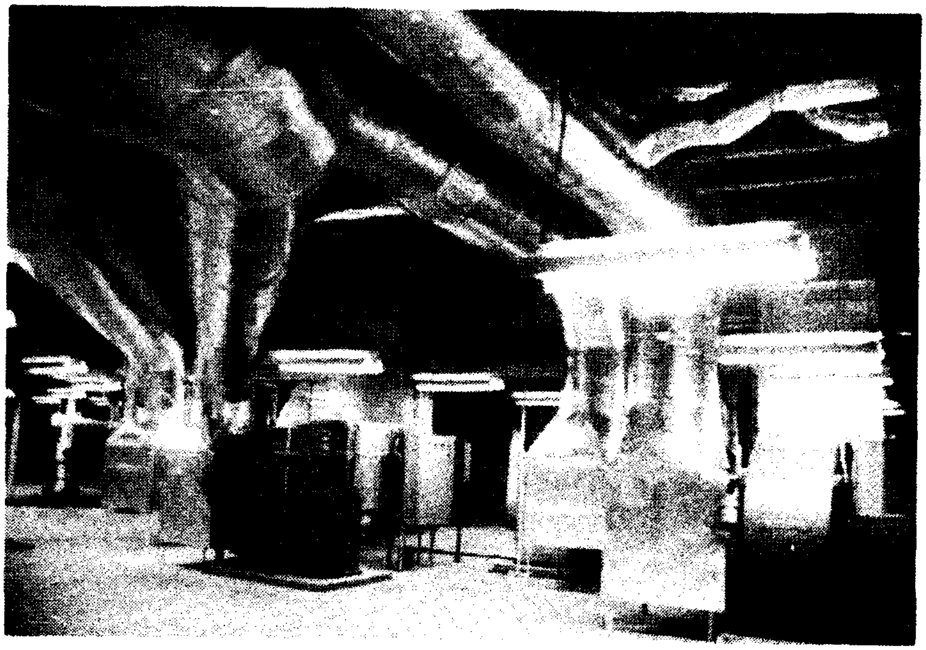


Figure 9. VAV Air-Handling Units (Second Floor).

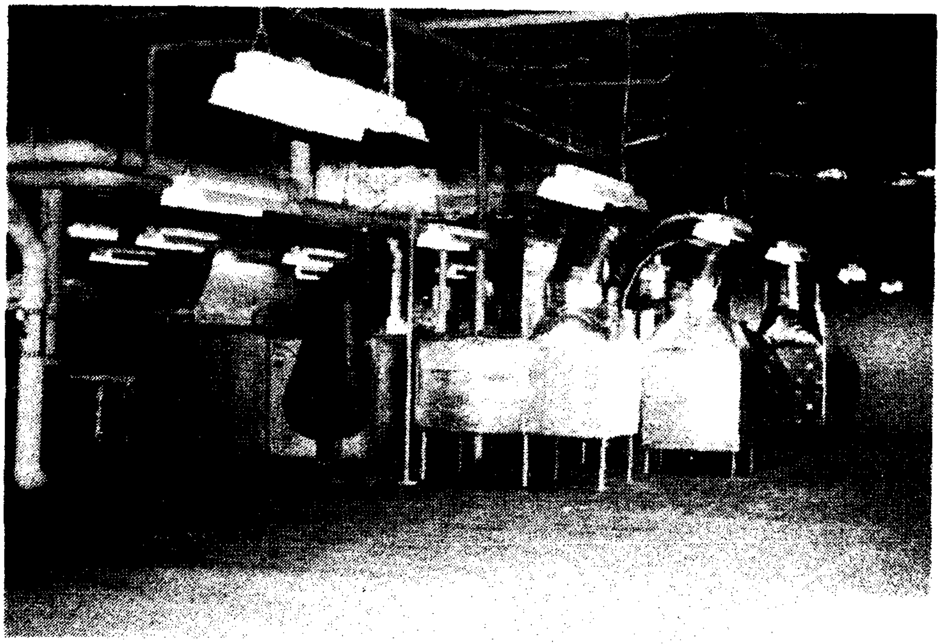


Figure 10. VAV Air-Handling Units (Third Floor).

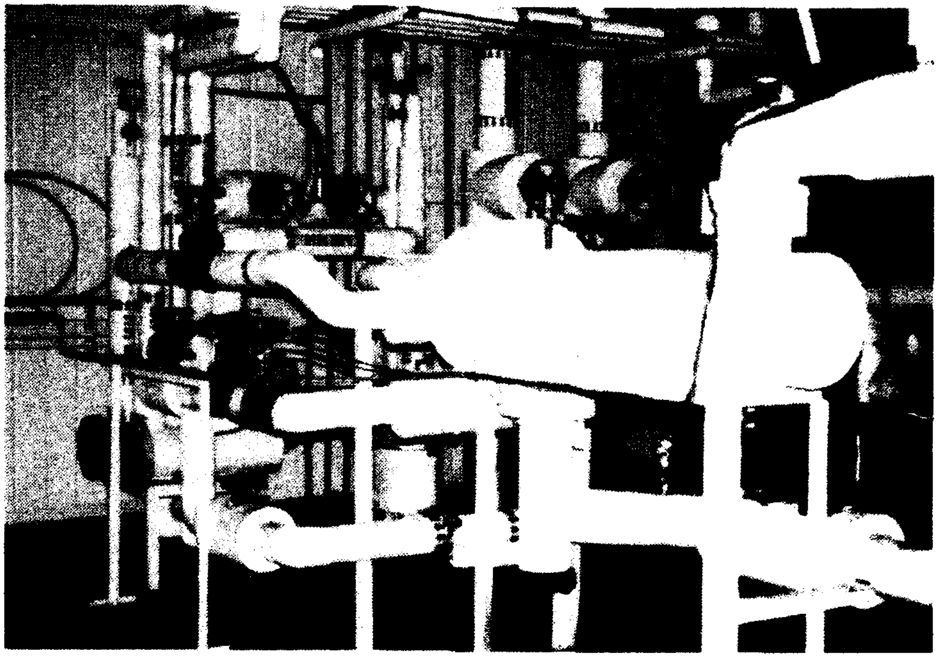


Figure 11. Heat Exchanger.

is brought back from the spaces through the return air duct and passes through the return fan; return air mixes with outside air (which is drawn in through the outside air duct) in the mixing section of the air handling unit; excess return air is exhausted through the relief air duct; and mixed air passes through the cooling coil, and is drawn through the supply fan. The supply air then makes its way through the ductwork to VAV terminal boxes that regulate the flow of air into the rooms to control room temperatures. AHU #2 had a design capacity of 14,000 cfm, with a static pressure setpoint of 2.5 in. of water column and a 55 °F setpoint for cooling-coil leaving-air temperature (supply air temperature). The VAV box-designed maximum air flow rates ranged from 440 to 1400 cfm. The constant-volume-with-reheat terminal units supplied heating to the hallways when required, and perimeter radiators provided heating in the rooms (Figures 13 and 14). Figure 15 and Tables 1 and 2 give other HVAC system information for the two AHUs.

Figure 16 shows a drawing of the heat exchanger that supplied hot water to radiation units, unit heaters, and terminal units throughout the building. A valve regulated the amount of high temperature glycol solution going to the convertor and thus the building's supply hot water temperature. The supply hot water temperature (SHWT) setpoint was reset according to the outside air temperature (OAT) based on the following schedule: at an OAT of 0 °F, the SHWT setpoint was 200 °F, and at an OAT of 30 °F, the SHWT setpoint was 165 °F. A pump was used to move the hydronic solution through the building.

The original control system used pneumatic controllers (Figure 17). The fan speeds were controlled by pneumatically actuated variable inlet guide vanes (Figure 18). The cooling coil valve and air dampers were also pneumatically actuated (Figures 19 and 20). All actuators had positive positioners like the ones shown in Figure 20. Sensing of supply and return air flows was done using annubars placed in the ducts.

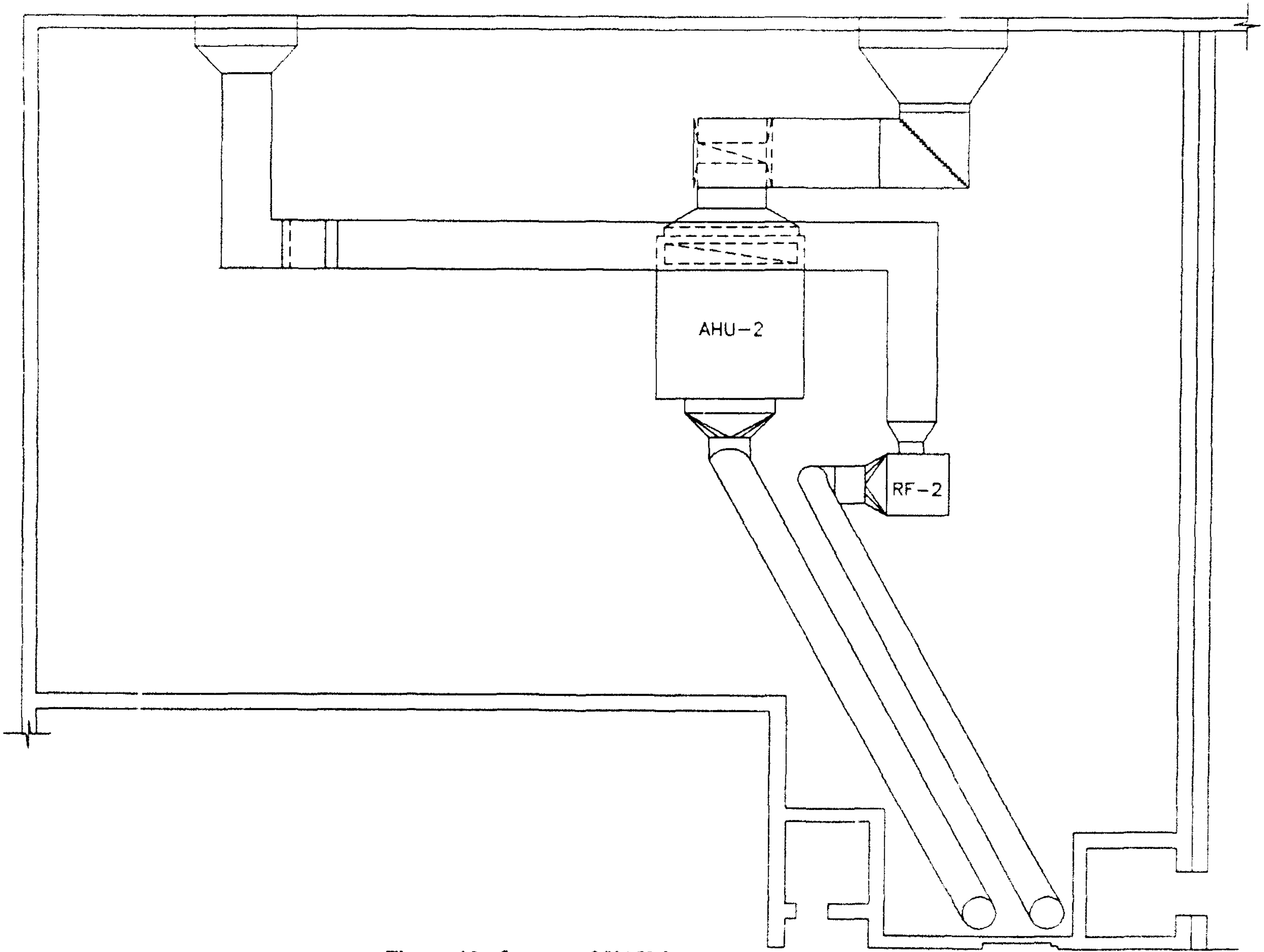


Figure 12. Layout of VAV System.

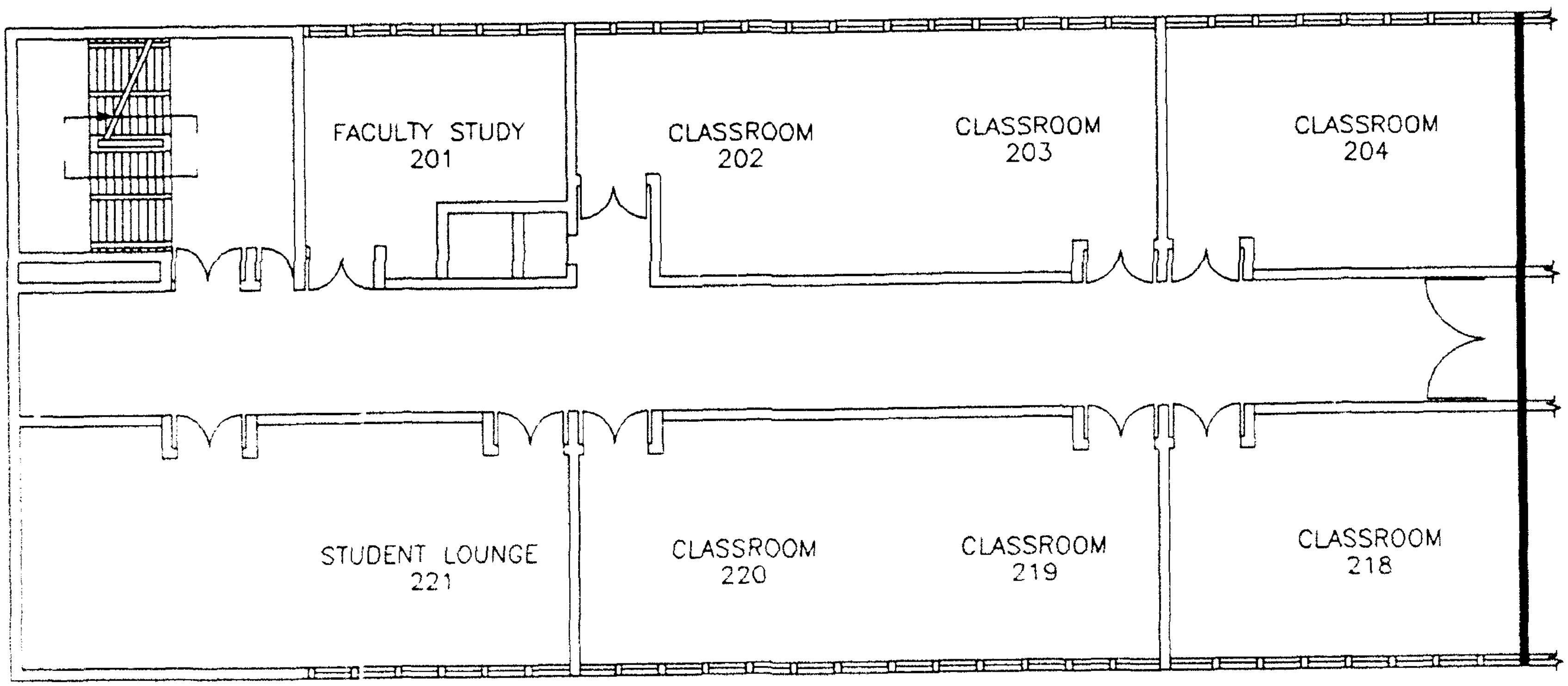


Figure 13. Layout of Second Floor–Southern Half.

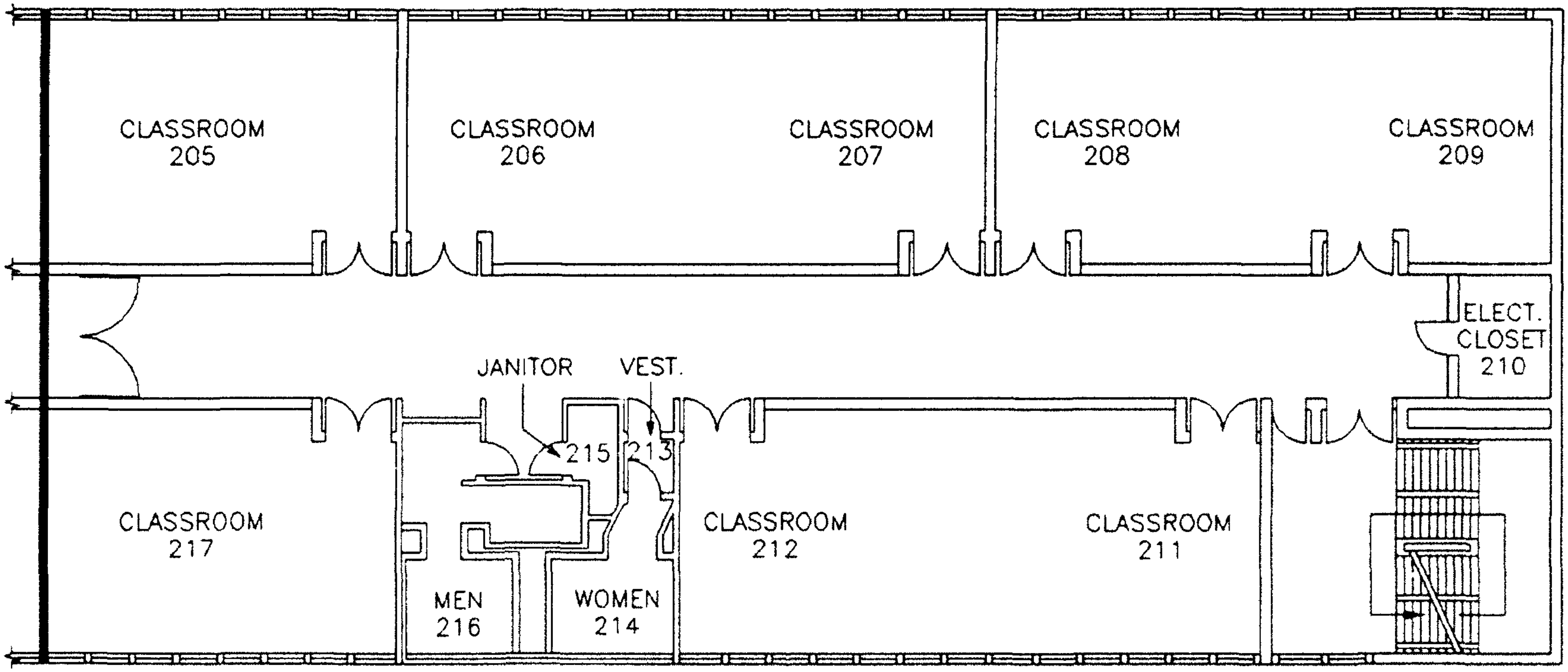


Figure 14. Layout of Second Floor—Northern Half.

AIR CONDITIONING UNIT SCHEDULE

UNIT NUMBER	CFM CAPACITY		EX. STATIC PRESSURE IWC	FAN	REMARKS
	TOTAL	MIN OA			
AHU - 1	14350	1500	3	INLET GUIDE VANES	VARIABLE AIR VOLUME
AHU - 2	14000	1500	3	INLET GUIDE VANES	VARIABLE AIR VOLUME

COOLING COIL SCHEDULE

UNIT NO	CAPACITY	ENTERING AIR TEMP		LEAVING AIR TEMP		MAX FACE VEL	EWT	LWT
	BTU HR	^{o}F DB	^{o}F WB	^{o}F DB	^{o}F WB	FPM	^{o}F	^{o}F
AHU-1	580000	79.5	66.6	55	56.5	550	45	55
AHU-2	560000	79.5	66.6	55	56.5	550	45	55

CFM = CUBIC FEET PER MINUTE
MIN OA = MINIMUM OUTSIDE AIR
IWC = INCHES WATER COLUMN
DB = DRY BULB
WB = WET BULB
FPM = FEET PER MINUTE
EWT = ENTERING WATER TEMPERATURE
LWT = LEAVING WATER TEMPERATURE

Figure 15. Schedules for Air Conditioning Units and Cooling Coils.

Table 1

Data on High Temperature Hot Water Heaters
at Fort Leonard Wood, MO

Unit	Capacity	High Temperature Water			Low Temperature Water		
Number	BTU hr	°F In	°F Out	GPM	°F In	°F Out	GPM
CV-1	2,500,000	350	225	43.9	180	200	250
CV-2	126,000	350	225	2.2	180	200	16

Table 2

Data on Pumps at Fort Leonard Wood, MO

Unit	GPM*	Heat Ft	Type	Remarks
P-1	250	45	Cent.	Hot water
P-2	16	25	Cent.	HW glycol
P-3	228	25	Cent.	Chilled water
P-4	6	25	In-line	Domestic HW

*GPM = gallons per minute.

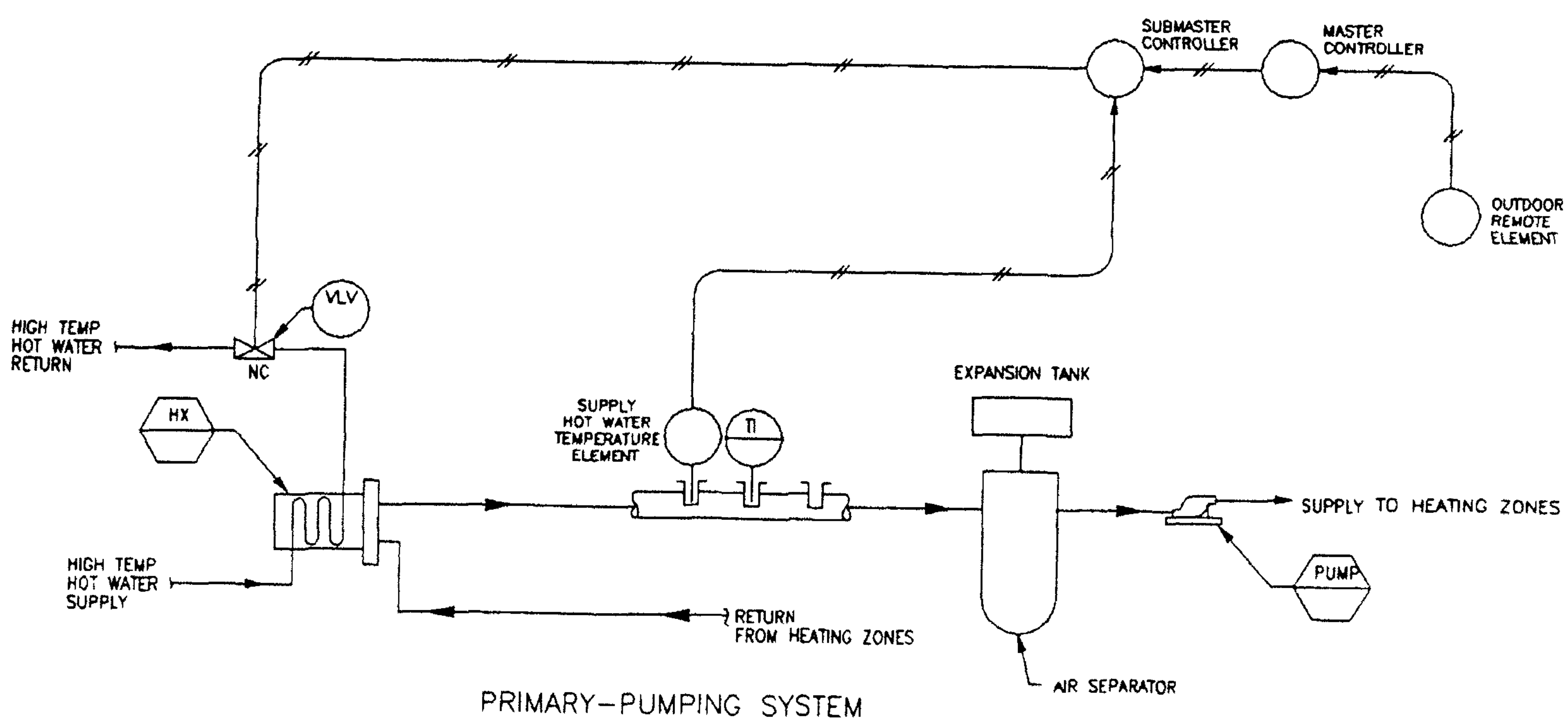


Figure 16. Schematic View of Heat Exchanger System.

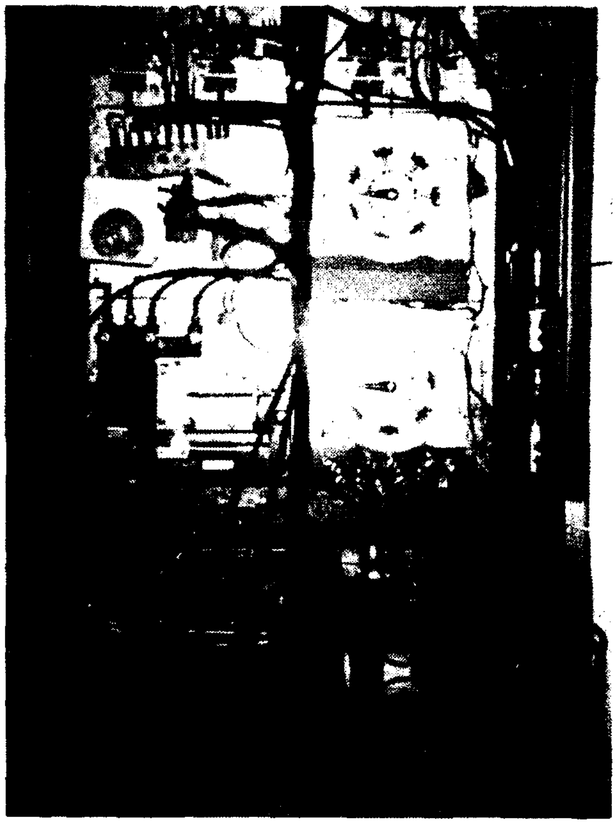


Figure 17. Original Pneumatic Control System.

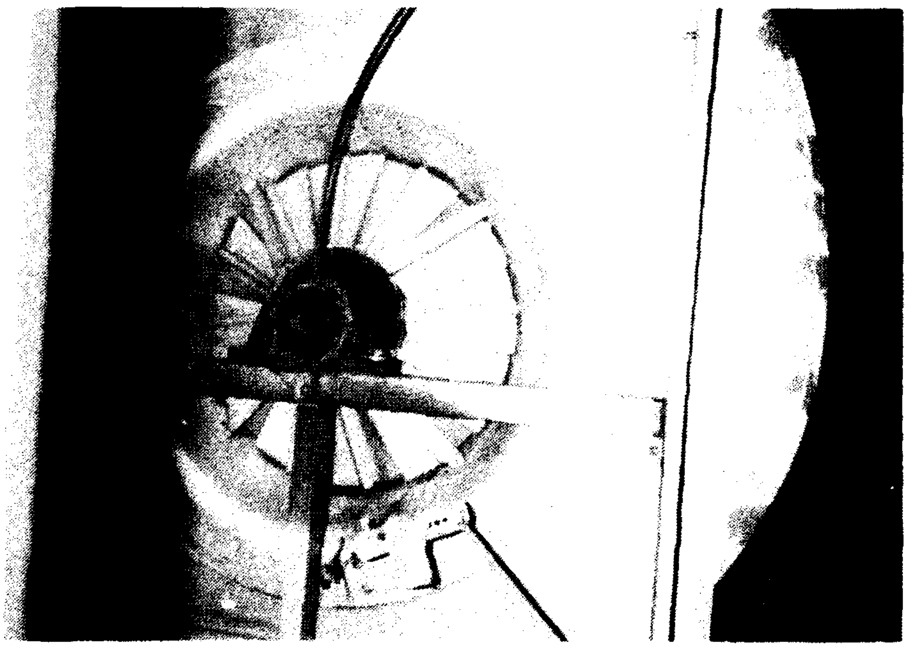


Figure 18. Fan Inlet Guide Vanes.

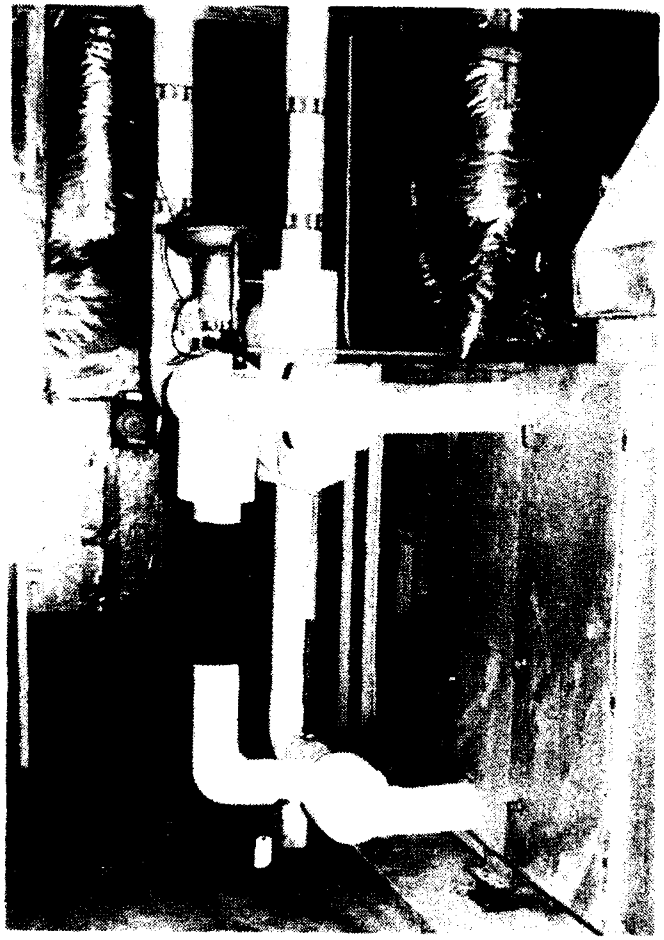


Figure 19. Cooling Coil Valve and Actuator.

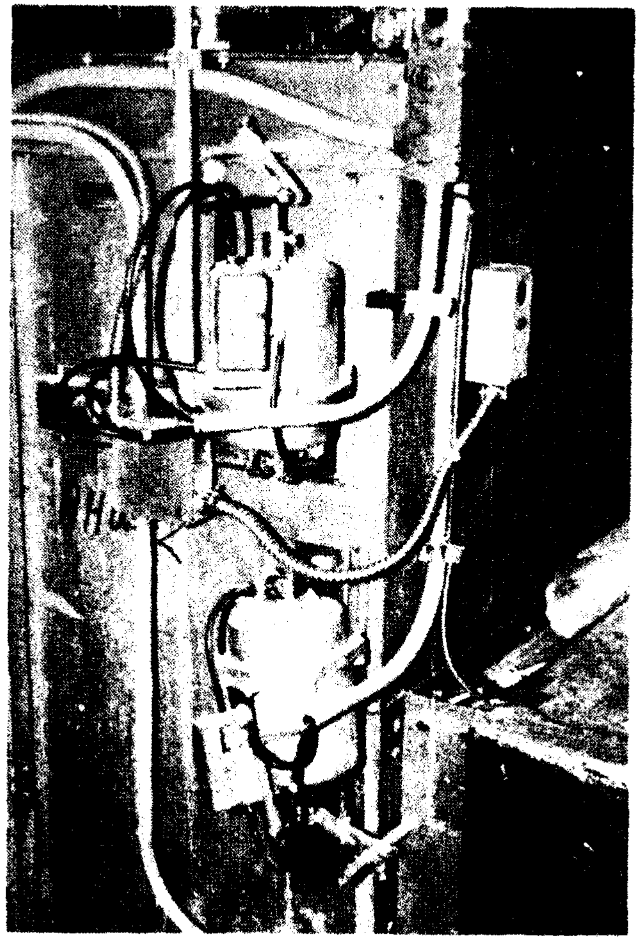


Figure 20. Air Damper Actuators and Positive Positioners.

The existing HVAC systems and their pneumatic controls were in good working condition, although the return fan control did not work very well and caused some building pressurization problems. The poor fan control resulted in uncomfortable space conditions in the winter when supply air volumes were supposed to be at minimum. These uncomfortable conditions sometimes resulted in the need to turn off the VAV systems. According to DEH personnel, the original enthalpy-based-economizer was disconnected and abandoned within the first year of operation because of faulty operation and high maintenance requirements. This was checked and it was confirmed that the system was only using minimum outside air when it was operating. In addition, previous studies on the system had found that the pneumatic controls did not hold the processes at setpoint.

Installation of the Standard Control System

The analog control systems and pneumatic control systems installed on AHU #2 and the heat exchanger systems were to be replaced during the project. The old control system was left in control while the new prototype standard system was being installed. The old wiring and pneumatic lines were identified and marked, and the wiring schemes were analyzed. Because of budget restrictions, the annubars were not replaced with air flow stations, but they were connected to pressure transducers that converted the air flow pressure signals to current signals for transmission to the panel.

It was found that the original mixed air temperature sensor had been incorrectly installed around a pipe and placed at the bottom of the MA duct section. The new MAT sensor was correctly serpentined across the duct as specified in CEGS-15950. The other temperature sensors were also installed as specified in the CEGS.

New conduit was installed and wires and pneumatic actuation lines were routed from the panel to the field devices, and the motor control center (Figure 21). Existing safety controls such as smoke alarms (Figure 22), the high static alarm, and the freeze stat were connected to the control panel. As specified in CEGS-15950, low voltage wires such as sensor wiring were run in dedicated conduit separate from higher voltage wires, such as 120 VAC, to prevent the possibility of induced current. Since the power circuit for the control panel was located in another room, an on-off switch was installed at the control panel to simplify disconnecting power to the panel. Figure 23 shows the panel during installation.

Once the wiring and pneumatic tubing were routed, the field device installed, and the connections to the panel were completed, the field devices were connected to the wiring and tubing, and existing unused control lines were fitted with pneumatic plugs.

Modification of the Control System During the Demonstration

The panel underwent many changes from the time construction first began in 1987 through 1991 when EMCS was connected to the panel. The changes reflected field experience, lab studies, and availability of devices.

During installation it was decided that position indication of valves, dampers, and other devices was cost prohibitive, therefore the position indication meters were removed and blank-off plates installed. Ratio and bias of the air flow signals was initially done using a function module. Ratio and bias of signals was determined to be an available option on SLDCs, so the ratio and bias function module that performed these functions was removed, and the controllers were reprogrammed to perform this function. This helped reduce the cost of the panel, simplify the system, and reduce the number of devices that might fail.

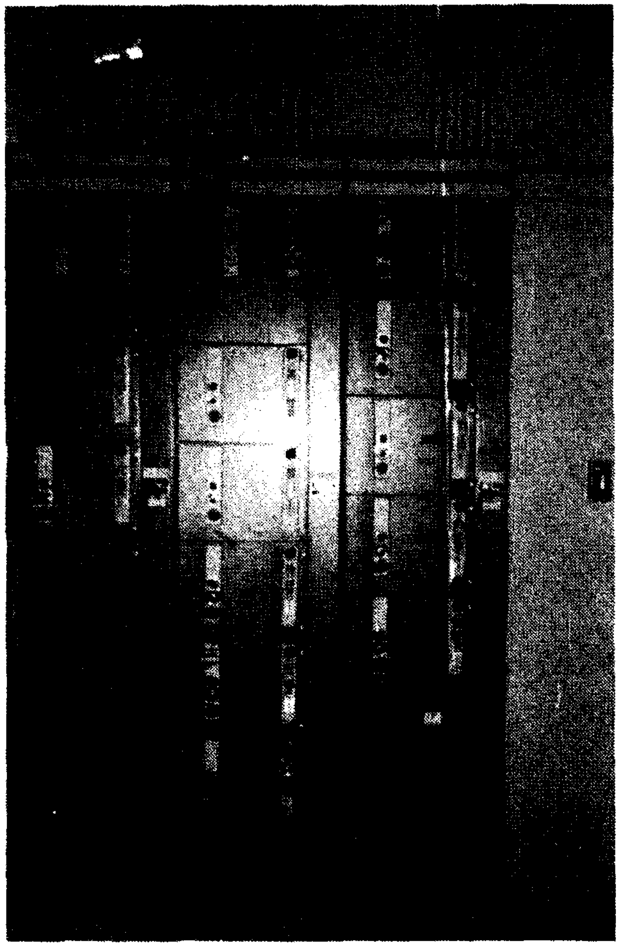


Figure 21. Motor Control Center.

Figure 22. Smoke Detector.

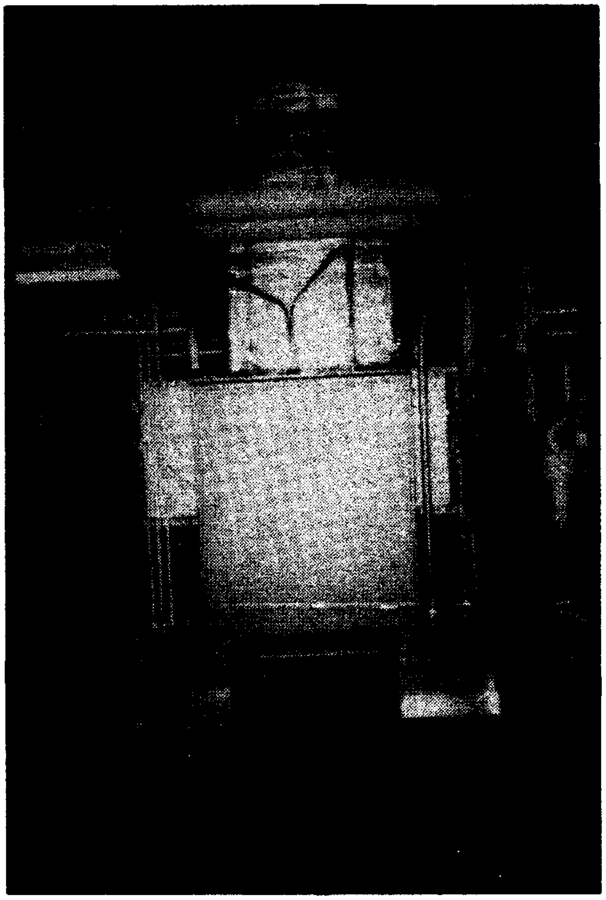


Figure 23. Control Panel During Installation.

Initially function modules were used to perform the hot water reset function, but were also replaced by a controller that could perform the function.

The relay logic of the fire control panel differed from the logic concept of the HVAC control panel. (A normally open contact existed where a normally closed contact was designed for.) This required the adaptation of an additional relay.

Appendix A contains the as-built versions of the sequence of operation for the systems, along with drawings showing the system configurations, ladder diagrams, front panel layout, and back panel layout.

Commissioning of the Standard Control System

Initial commissioning of the systems began in early 1988 and continued until early 1989 due to modifications of the control systems. The standard control system remained in control of the HVAC

system during the period. Commissioning, as described in CEGS-15950, consisted of calibration of: sensor/transmitter assemblies for the static pressure, air flows, and temperatures loops; adjustment of actuator/pilot positioner assemblies for valves, dampers, and inlet guide vane dampers; setup and configuration of controllers and the time clock; setup of alarm and other devices; tuning of controllers; and checking of the sequence of operation. Setting of the minimum outside air was also performed during commissioning.

During the commissioning process, there was some difficulty in achieving the design maximum supply air flow volume. After some troubleshooting and analysis, the problem was identified as a loose supply fan belt. After the fan belt was fixed, it was determined that the system still had trouble maintaining the supply static pressure and return maximum air flow setpoints under certain conditions. It was discovered that the supply fan could not achieve the supply static pressure setpoint when the return air dampers were open, but at the same time, the return fan could achieve the return air flow setpoint. Conversely, the supply fan could achieve the static pressure setpoint when the return air dampers were closed, but the return fan could not achieve the return air flow setpoint with the return air dampers closed. The controls were found to operate correctly, so it was believed that this was a result of either an incorrect design or an incorrect installation of the duct and dampers. The incorrect duct and damper sizes would cause different pressure drops in the system depending on whether the return air was being exhausted or recirculated. The deviations from setpoint were minimal and would have little effect on total system performance, so no steps were taken to correct the problem.

Appendix B contains the commissioning procedures and report for the systems at Fort Leonard Wood. CEGS-15950 contained "initial" commissioning procedures, which were to be expanded upon by the contractor, following the format of the CEGS commissioning procedures. USACERL researchers expanded on the commissioning procedures, but found it necessary to deviate from the predeveloped format. The commissioning procedures were reproduced and included in the Operation and Maintenance Manual provided to Fort personnel for use in component repair, replacement, or recalibration.

Performance Verification of the Standard Control System

The CEGS required that the contractor demonstrate compliance of the HVAC control system with the contract documents as part of the performance verification test (PVT). The CEGS also required that the contractor develop PVT Procedures that explained the actions and expected results that demonstrated compliance. Normally, the PVT procedures would have been submitted to the Government beforehand for approval, but since USACERL was acting as both contractor and Government official, and had developed and approved the PVT procedures, this was not required. The PVT was conducted with the Fort personnel to show them that the system was working correctly.

Appendix C contains the "Performance Verification Test Procedures and Report" for the systems at Fort Leonard Wood. It took a significant amount of time and experience to develop PVT procedures that produce a correct and sufficiently detailed document. The document was reproduced and included in the Operation and Maintenance documentation provided to Fort personnel for use in periodic checks of system operation, and to determine when calibration, adjustments, and repairs were necessary.

Training of Operation and Maintenance Personnel

The CEGS, at the time, required that a 16-hour training course on the operation and maintenance of the control system be conducted. The attendees were assumed to have at least a high school education

and to be familiar with HVAC systems. The training course was to cover all material located in the operation and maintenance manual and to cover the layout and location of equipment.

The course was conducted in June 1989 and the attendees included DEH technicians, personnel from the Fort's maintenance contractor, and FORSCOM personnel. Because this was the first standard SLDC system installed, and because some of the attendees had no prior knowledge of the system, the course began with an introduction to the panel, a review of early research, a review of basic concepts, and a discussion session. Some additional basic control information was also discussed. The basic concepts of the training course were to first familiarize the students with the system designs, its operation, and the system documentation. The students would then receive specific training on how to operate, maintain, and repair the system equipment.

To familiarize the students with the equipment, a tour of the mechanical room was given noting the location of mechanical equipment, field control equipment, and control panel equipment. Back in the classroom, an overview of the system documentation was given to familiarize the students with the contents. This included an overview of the operation and maintenance manual, the equipment data booklet, shop drawings, commissioning procedures and report, and the performance verification test procedures and report.

The first day continued with a review of the HVAC system sequence of operation. Next, a review of the single-loop digital controllers and time clock was given, including configuration and setup procedures. The first day concluded with a review of other control equipment. The second day included a repetition of the performance verification test as a functional description of how the system operated. The remainder of the day included both classroom and mechanical room sessions dealing with maintenance and troubleshooting procedures.

Standard HVAC Control System Documentation

Equipment data books, operation manuals, and maintenance manuals were used during the training course, and copies were delivered for the facility archives. Spare parts, including an SLDC, function modules, and time clock were also left with DEH personnel. Figures 24 and 25 shows the tables of contents for the operation manual and for the maintenance manual.

The shop drawings included in the Operation Manual were:

1. VAV control system schematic, equipment schedule, bill of materials
2. Cooling coil DAT wiring diagram, SHWT wiring diagram
3. MAT wiring diagram, economizer wiring diagram
4. SDSP wiring diagram, RF wiring diagram
5. Ladder diagram, sequence of operation
6. HW control system schematic, equipment schedule, bill of materials
7. List of symbols, drawing index
8. Relay, interlocks, and MCC wiring diagram
9. Power strip wiring diagram
10. Back panel layout.

Shop Drawings 1, 5, and 6 were laminated and posted as specified.

Fort Leonard Wood
Operation Manual
Single Loop Digital Control Panel
Brown Hall, AHU-2, HW-1

TABLE OF CONTENTS

Figure 24. Operation Manual Table of Contents.

Fort Leonard Wood
Maintenance Manual
Single Loop Digital Control Panel
Brown Hall, AHU-2, HW-1

TABLE OF CONTENTS

Figure 25. Maintenance Manual Table of Contents.

Connection of the Standard Control System to EMCS

Installation of an EMCS at Fort Leonard Wood was completed in 1991. Brown Hall was one of the buildings connected to the EMCS, and both air handling units were connected. Optimal start/stop and demand limiting were the primary programs to be used by the EMCS. This was accomplished by a contact connected in series with the supply fan motor starter. The return fans were wired to the Supply fans through an auxiliary contact and would not run unless the supply fan motor starter was energized. During demand limiting, the units were turned on and off for varying durations several times a day.

Evaluation of The Standard HVAC Control System Performance

Several return visits have been made since completion of installation and commissioning in June 1989. All controllers and other devices have worked accurately without any failures. The PVT was repeated and found the sensing accuracy to still be within specifications, other devices have remained in calibration, and control of processes was still being achieved,

The time clock used in the panel had a battery backup duration of 12 hours. This no longer meets the specifications of CEGS 15950, which requires a battery backup duration of 4 days. The experience at Brown Hall shows why this backup is needed. Several times during the course of the project, power to the panel was turned off for over 12 hours. This resulted in the time clock losing its program and having to be reprogrammed.

USACERL was notified that on occasion, during the winter when a large number of people were in the classrooms, the return air temperature rose above the economizer summer/winter switchover temperature setpoint when the outside air temperature was low and resulted in the Economizer activating. This resulted in more than minimum outside air being brought into the AHU and in 55 °F air being supplied to the spaces. It is likely that more than minimum outside air was required for ventilation purposes in the classrooms where the large number of people were located, but maybe not as much as was brought in, and probably not for the rooms that were not highly occupied. This problem was more a result of building use patterns and HVAC system design than one of controls. Fort Leonard Wood personnel were advised that one option to correct this problem would be to raise the mixed air temperature setpoint up to 65 °F during the winter. Another less desirable choice, which would use more energy, would be to install a VAV with reheat terminal boxes. With the connection of EMCS to the control system the Fort now has the ability to override the Economizer function.

Fort Leonard Wood personnel raised the issue of using cool outside air during the morning rather than not using any outside air during the delayed ventilation mode. Although there wasn't a standard control system design for this function, it was studied and is now available. Fort Leonard Wood now has the ability to do this through the EMCS.

4 LESSONS LEARNED DURING THE FORT LEONARD WOOD DEMONSTRATION PHASE

The intent of this phase of the project was to evaluate and demonstrate the prototype control panel design and control system equipment. During the construction, installation, and commissioning of the control system, USACERL gained insight into how the designs could be modified, and component specifications changed so that the size and cost of the panel would decrease. At the same time, other research was being conducted, which also led to changes in the panel designs, TM 5-815-3 and CEGS-15950. Some of the findings and changes are discussed below.

Panel Size

The original intent of the design of the panel was to accommodate all panel control devices for all the possible standard control system designs and also to include various diagnostic features. It became obvious that the panel was physically too large and cumbersome for many mechanical rooms and required large mounting hardware, so the decision was made to change the design. Having two panel designs would have violated the concept of a single standard design and would have increased manufacturing costs. The overriding objective was to produce one simple design. Emphasis was placed on reducing the size of the panel by rearranging and deleting components, and by conserving space where possible.

Panel Equipment

Lab research determined that the electronic meter for indicating the outdoor air temperature could be eliminated since the controllers could display both process and remote variables. Further research revealed other features of the SLDC controllers that helped eliminate some signal-conditioning devices. Position indication proved to be impractical to implement because of high cost, so it was deleted from the panel designs. Modular pilot lights and switches replaced the earlier specifications for industrial-type lights and switches.

Panel Features

The devices mounted on the inner door were found to be heavy enough to cause the typical two-hinged doors to sag and eventually scrape against the bottom of the panel. Continuous, piano-type hinges were found to alleviate this problem and were incorporated into the design documents. The final version of the panel design will be discussed in Chapter 5.

Nonstandard Systems

Sometimes existing field equipment does not match up with the standard designs, especially for retrofit projects. This was the case at Brown Hall with the low temperature alarm wiring, and the smoke alarm wiring. It was necessary to modify the wiring scheme, add additional relays, and develop as-built wiring diagrams so that the control system would work correctly. Performing changes in the field is typically expensive, time consuming, and sometimes difficult, so identification of nonstandard situations such as this is desirable in the design phase.

Retrofit Guidance

A document providing information to assist the designer with evaluating the existing HVAC system and HVAC control system would be useful. Information and checklists to help survey the systems to determine their condition, what equipment can be reused, and what equipment should be replaced would help streamline the design process and help ensure that a correctly functioning HVAC system is installed.

Documentation Specifications

CEGS 15950 contains a section that provides specifications concerning submittals and other system documentation that the contractors are to produce and supply to the Government. During preparation of documents for Fort Leonard Wood, USACERL researchers found that this section could have been worded more simply and directly. Some of the submittal specifications needed more specificity to avoid the poor system documentation that could result in an incorrectly operating system and could inhibit the maintenance personnel's understanding of the control system. A report is being prepared that deals with the whole submittals section of CEGS 15950

Commissioning Procedures

The commissioning procedures in the CEGS were found to be a sufficient starting point to develop more detailed procedures. In the CEGS, the specifications state that the contractor should add information by detailing the steps involved in commissioning. Requiring the contractor to add this information increases the cost of the documentation significantly since an engineer is likely to be involved in the development. Enforcing this requirement would also be difficult. USACERL researchers' experience from this phase of the project determined that it may be possible to develop detailed commissioning procedures at the predesign or design phase of a project. This would help decrease the cost of the control systems by reducing the contractor's development time. At the same time, it would increase the knowledge of the control systems by the designer, construction representative, contractor, manufacturer, quality verification personnel, and maintenance personnel. It would also help ensure that the system would be correctly setup, calibrated, and tuned.

Performance Verification Test Procedures

The CEGS states some requirements about what the PVT Procedures should show. These requirements are sufficient as a starting point to develop detailed PVT procedures; however, it was found that later in the process, more guidance and information was needed. It would be difficult to ensure that the Government received good PVT procedures from the contractor, and bad procedures could lead to acceptance of incorrectly performing HVAC systems. The experience of USACERL researchers from this phase of the project determined that it may also be possible to develop detailed PVT procedures at the predesign or design phase of a project. This would help to decrease the cost of the control systems by reducing development time by the contractor.

During commissioning of the control system, other mechanical and HVAC equipment must be working properly for the system to be correctly commissioned. When the Brown Hall HVAC system could not supply the maximum design air flow, initially, control devices were thought to be operating incorrectly. The controls were found to be operating correctly and the loose fan belt was identified.

5 DEMONSTRATION OF HVAC CONTROL PANELS AT FORT CAMPBELL, KY

Background

Kuhn Dental Clinic at Fort Campbell, KY was selected for the second phase of the standard HVAC control system demonstration project. Since the beginning of the project, several revisions to the CEGS and TM had been made, especially the design of the panel. These revisions, and the nearing completion of the CEGS and TM made it desirable to perform another evaluation of the standard HVAC control systems. This time the effort would concentrate more on evaluating the ability of the CEGS and TM to be used by other Army personnel in designing and contracting out jobs, as opposed to the first phase of the project, which dealt mostly with evaluating the equipment. Another objective of the second phase was to evaluate the ability of the CEGS, TM, and drawings to be interpreted correctly by contractors.

Overview

This phase of the project began in February 1989 with a survey of several buildings at Fort Campbell, and the selection of Kuhn Dental Clinic as the demonstration site. An Energy Survey was conducted to evaluate the condition of the existing control system, HVAC system, and the building in May 1989. The design was completed and sent out for bids in August 1989, and the bid was accepted in September 1989. Submittal review was completed in October 1989, and panel construction was completed in January 1990. Installation of the control system was delayed for 2 months for removal of asbestos pipe insulation, and installation was completed in April 1990. The system was commissioned and the PVT was conducted in May 1990, with training following immediately afterwards. Several return visits and conversations with Fort Campbell personnel have confirmed accurate control of the HVAC system.

Coordination of the Project

This phase of the project began with a discussion between Fort Campbell DEH personnel and USACERL personnel. USACERL researchers explained that their objective was to evaluate the CEGS and TM as well as the actual control system. USACERL would provide funding to the DEH to design, procure, and install the new control system. A DEH designer was to prepare the design and contract package while USACERL provided assistance in the form of reviews. This process would provide insight into how understandable the CEGS and TM were to someone unfamiliar with the documents. USACERL would continue to provide assistance during the submittal review, installation, commissioning, and performance verification (acceptance) testing phases.

Selection of the Building and HVAC Systems

Kuhn Dental Clinic was selected as the demonstration site for several reasons: (1) the HVAC system's similarity to a standard multizone HVAC system; (2) the poor state of the existing HVAC control system; (3) the availability of the building's EMCS so interfacing with the standard HVAC control system could be investigated; and (4) because the single floor building would simplify analysis. At the same time, several disadvantages to conducting the project at the Kuhn Dental Clinic building were noted: (1) the old HVAC system was likely to have problems other than control system problems, which might inhibit the ability to fully evaluate the new control system performance; (2) the mechanical room was small and could present functional problems; (3) the building had variable occupancy; (4) the building was powered by central supply plant steam; (5) it would be difficult to account for the interaction of other

HVAC systems with the multizone system; and (6) the interaction of the perimeter heating units with the multizone system could affect evaluation performance.

Description of the Building and HVAC Systems

Kuhn Dental Clinic is a single story, 11,000 sq ft brick building built in 1962 (Figure 26). The building contained offices, examination/operating rooms, surgical rooms, a prosthetics laboratory, X-ray rooms, an administrative area, and a waiting area. A layout of the building is shown in Figure 27.

Heating, cooling, and ventilation was supplied by a single-zone AHU, a five-zone multizone AHU, a heat pump, and perimeter radiation units. Figure 28 shows the building HVAC zones.

Hot water for the multizone system and radiation units was provided by a convertor located in the basement. The convertor was designed to heat 86 gpm of water from 180 °F to 200 °F using 10 psi steam from a central energy plant. Figure 29 shows a schematic of the convertor system (central-plant steam hydronic-heating control system). A steam valve regulated the amount of steam going to the convertor and thus the supply hot water temperature. The supply hot water temperature (SHWT) setpoint was reset according to the outside air temperature based on the following schedule: at an outside air temperature (OAT) of 0 °F the SHWT setpoint was 200 °F, and at an OAT of 75 °F the SHWT setpoint was 85 °F. Supply hot water from the convertor was piped in parallel to the multizone (MZ) unit heating coil and the radiation units. A pump was located in the return line of the MZ heating coil loop and designed to pump 68 gpm of water through the loop. A pump was located in the return line of the radiation units loop and designed to pump 10 gpm of water through the loop. The system was controlled by the original pneumatic control system installed in 1962. The pneumatic controls used a master/submaster type controller (Figure 30), to perform reset of the SHWT. Temperature sensors were capillary type and valves did not have positive positioners.

The building had a dedicated chiller, installed in the summer of 1987 to provide chilled water for cooling. The chiller had replaced a cooling tower system and was designed to deliver 42 °F water. Supply cold water from the chiller was piped in parallel to the multizone and single-zone cooling coils. The chiller was not studied during this project.

The single zone unit supplied only the surgical area of the building with 1275 cfm of air, and was designed to use 100 percent outside air. The single zone (SZ) AHU was located on the main floor (Figure 28). The SZ used steam from the central heating plant and chilled water from the chiller. Exhaust fans removed 1270 cfm of air from the area served by the SZ system. Although the single zone system was briefly studied, it was not retrofitted with controls as part of this project.

The DEH was in the process of installing a 5-ton heat pump to supply cooling and heating for the prosthetics laboratory as the demonstration project was beginning. The Prosthetic Lab had been experiencing problems with being too hot. This was blamed partially on the fact that processes in the Lab generated a lot of heat, and because the multizone system provided inadequate cooling. The heat pump had been planned for some time and was not studied as part of the project.

The five-zone multizone AHU supplied the rest of the building and was located in the basement mechanical room. The zone-duct supplying the prosthetics lab was shut off when the new heat pump was added. Figure 28 shows the areas served by the multizone unit and the HVAC zoning of the building. Grills in the room doors allowed air to exit the rooms and enter the hallways. Return air was brought back through the halls to a grill located in the wall of the room housing the single-zone system (Figure 28). The return air would then pass through another grill in the floor of the room and enter the MZ return

air duct. Design air flow for the system was 11,925 cfm. The building had 11 exhaust fans with a total capacity of 4625 cfm. With all main floor exhaust fans operating, including those in the SZ-supplied rooms, the MZ return air volume would be 8575 cfm. The single-zone system was designed for 100 percent outside air, so the make-up outside air (minimum OA) for the multizone system was 3350 cfm, or 28 percent outside air. Exhaust registers located in the ceiling allowed for building air to exhaust when the return air dampers were closed during economizer operation.

The MZ system was controlled by the original pneumatic control system installed in 1962. The pneumatic controls included a Master/Submaster type controller to perform reset of the hot deck temperature according to the outside air temperature. The controls also included an economizer controller that based its operation on temperature. The system had a winter/summer switchover to disable the economizer. The OA and RA dampers were operated from the same actuator. The temperature sensors were capillary type, and the valves and damper actuators did not have positive positioners.

A three-way mixing valve on the hot water supply line to the MZ heating coil mixed supply and return hot water to maintain the hot deck discharge air temperature at setpoint. The valve was to be replaced as part of the project. The MZ system was designed to heat 11925 cfm air from 52.8 °F to 105.5 °F when using 68 gpm of 200 °F water (679,300 BTUH). The hot deck was designed for the following schedule: at an OAT of 0 °F, the HDT setpoint was 140 °F; and at an OAT of 75 °F, the HDT setpoint was 80 °F.

A three-way mixing valve on the cold water supply line to the MZ cooling coil mixed supply and return cold water to maintain the cold deck discharge air temperature at setpoint. The valve was designed to be replaced as part of the project. The system was designed to cool 11925 cfm air from 82.3 °F dry

Figure 26. Kuhn Dental Clinic, Fort Campbell, KY.

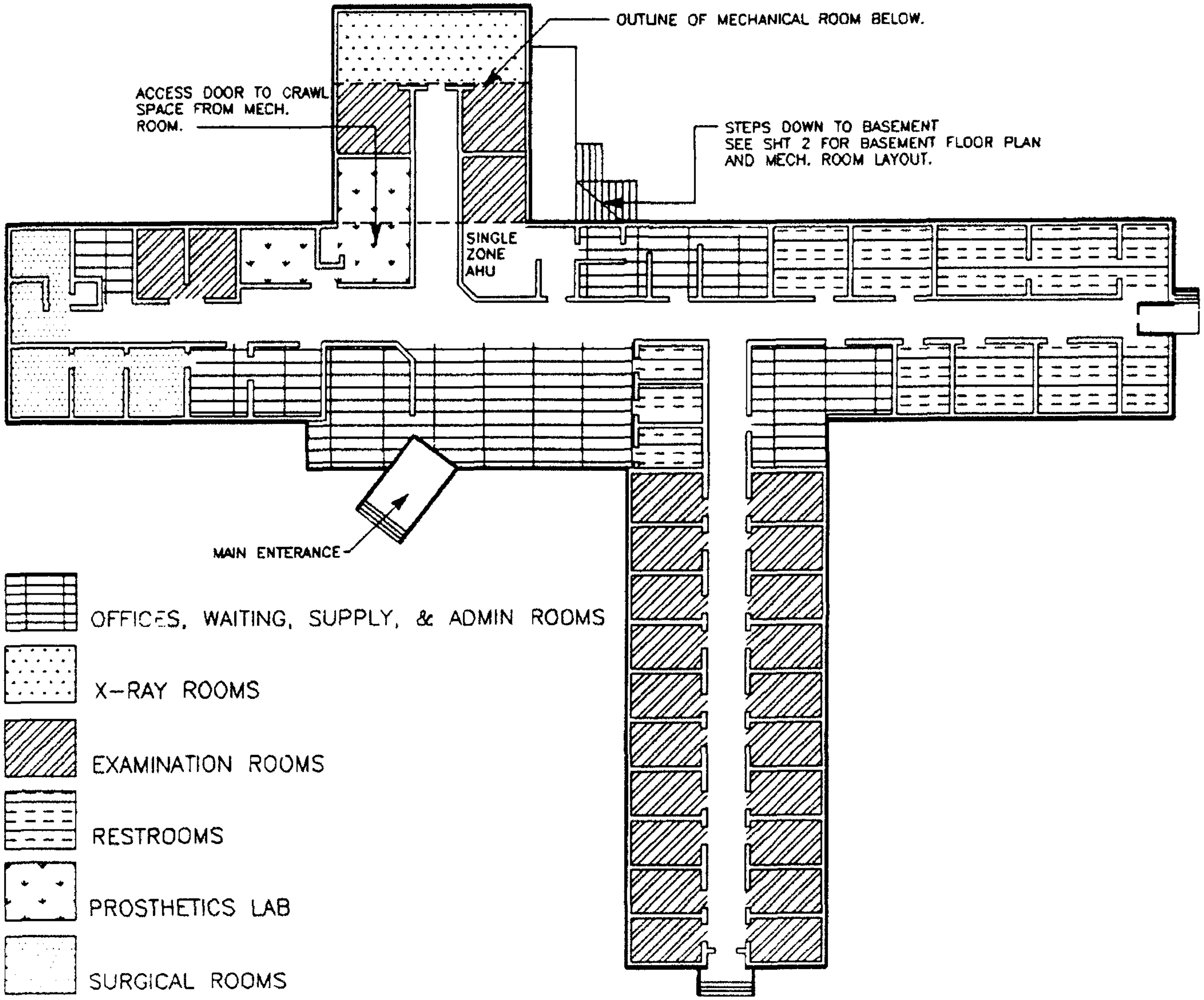


Figure 27. Kuhn Dental Clinic Building Layout.

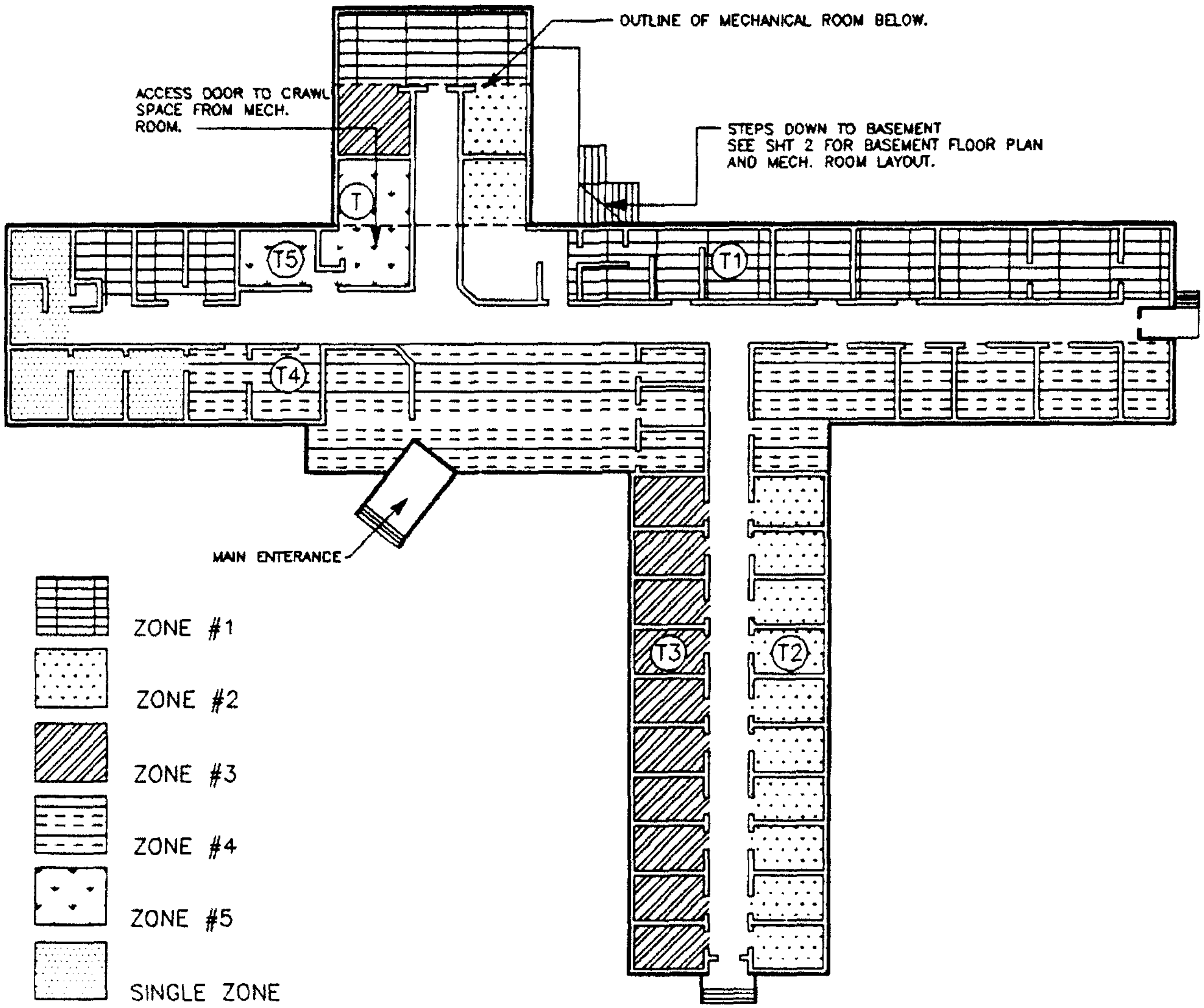


Figure 28. Kuhn Dental Clinic Building HVAC Zones.

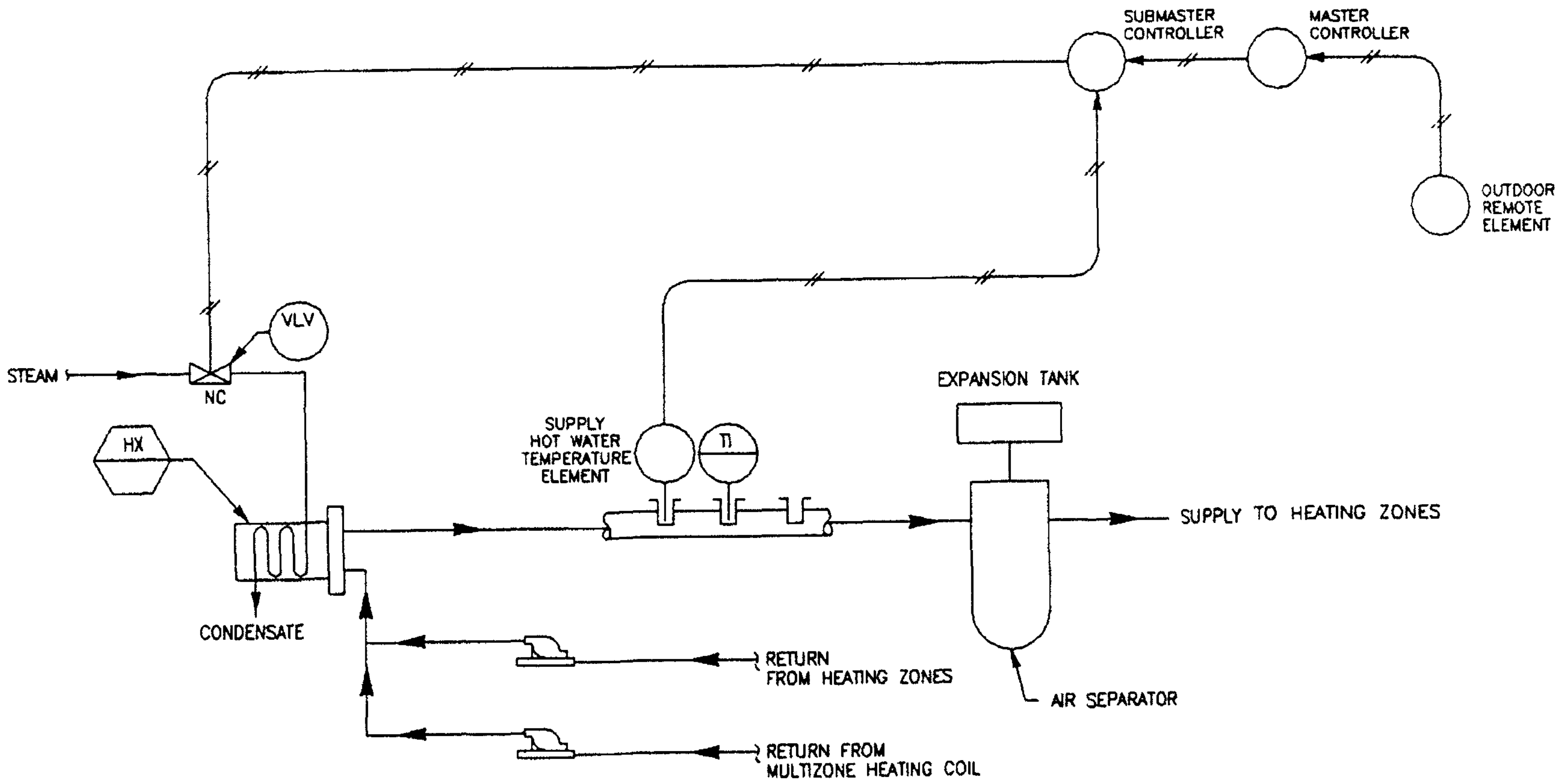


Figure 29. Schematic View of Convertor System.

bulb and 68.3 °F wet bulb to 55 °F dry bulb and 53.4 °F wet bulb when using 139 gpm of 42 °F water (554,500 BTUH).

The zone dampers were controlled by pneumatic actuators that received a positioning signal from pneumatic thermostats located in the zones (Figure 31).

Zone #1 supplied air basically to the east-facing rooms of the building. The design flow was 2420 cfm. Four exhaust fans removed 1710 cfm of air. The thermostat for the zone was located in the supply room, and seven radiation units were located in this zone (Figure 28).

Zones #2 and #3 supplied air to south and north facing rooms, respectively. The design air flows were 2855 cfm for Zone #2 and 3035 cfm for Zone #3. The thermostats for the zones were located in rooms midway down the halls (Figure 28).

Zone #4 supplied air to the west-facing rooms. The design air flow was 3130 cfm. The thermostat for this zone is located in the office. Exhaust fans in the Conference Room and Restrooms removed 1090 cfm of air. Several radiation units are located in this zone.

Zone #5 supplied air to a few interior rooms. The design air flow was 485 cfm. The thermostat for this zone is located in the X-ray room. An exhaust fan in the darkroom removed 140 cfm of air.

Energy Survey Findings

According to base personnel, this building had experienced HVAC problems over the last 5-year period. The complaints were that the building was too hot in the summer and too cold in the winter. During mild periods, the room temperatures were comfortable but during extreme temperatures the rooms were uncomfortable. For the 22 years leading up to the last 5 years, the HVAC system had been able to maintain space temperatures.

The clinic personnel were concerned about the high temperatures experienced in the building for the following reasons:

1. Adverse patient reactions
2. Impotency of anesthetics
3. Unreliable dental materials
4. Increased surgical bleeding
5. Cancellation of high risk patients
6. Reduced productivity
7. Reduced patient satisfaction
8. Lower staff morale and energy
9. Wasted money from material spoilage.

They were also concerned that any reduction in outside air ventilation might lead to unhealthy levels of mercury and other chemicals in the building.

Past experience of USACERL researchers has shown that the controls are sometimes falsely blamed for problems due to incorrect design, failing HVAC equipment, or improper air balancing. USACERL researchers interviewed several building occupants, measured air flows, and investigated the HVAC system and building.

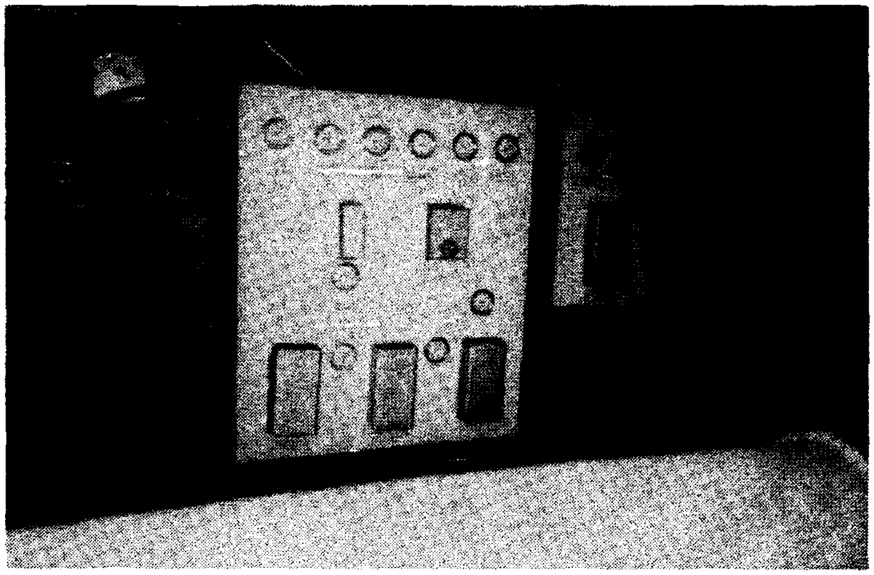


Figure 30. Existing Pneumatic Controls.

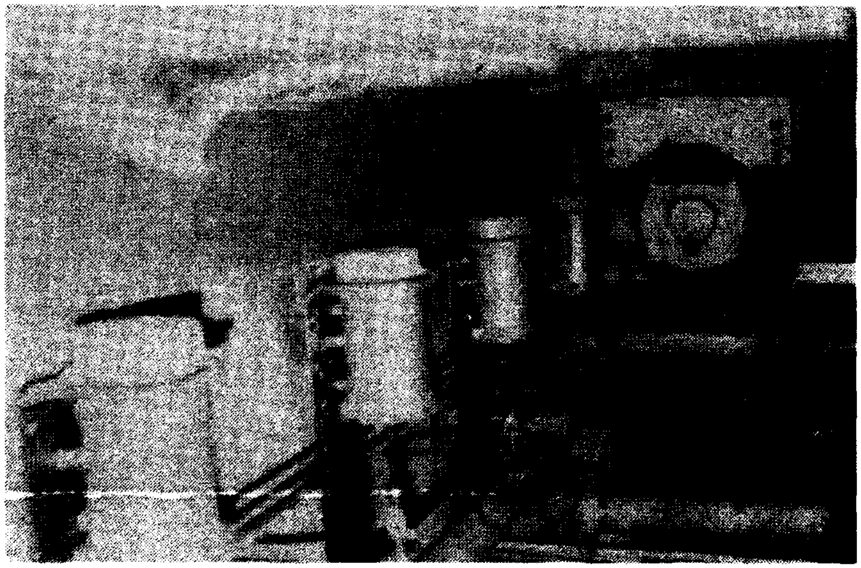


Figure 31. Multizone Zone Damper Actuators.

A crawl space underneath the building floor was used to route steam, water, vacuum, and other utility lines. The crawl space occupied the entire area of the building except for where the mechanical room was located.

In the crawl spaces beneath the operating wing floor, a steam leak was discovered that was raising the crawl space temperature in the area of the leak to 96 °F (Figure 32). The occupants of the room directly above the steam leak said that the room was always warmer than the other rooms in the area. Temperature measurements found the room temperature above the leak was 74 °F and the floor temperature was 84 °F. Temperature measurements in the room across the hall found that, although the room temperature was warmer (77 °F), the floor temperature was only 73 °F, so the room felt more comfortable.

A steam valve was leaking in the crawl space beneath the Administration area causing the ceiling temperature in the crawl space area of the leak to be 87 °F. A pressure relief valve was also located at that point and vented directly into the crawl space when the pressure was above its setpoint.

A pair of vacuum pumps underneath the prosthetic lab floor were found to be venting hot air into the crawl space instead of outside (Figure 33). This resulted in crawl space ceiling air temperatures in the areas around the pumps to be as high as 120 °F, at an OAT of 65 °F. Interviews found that the prosthetic lab rooms were sometimes too hot and never cool enough. Suggestions were made that the pumps be vented to the outside. This was accomplished and on a return trip in August, the temperature at the ceiling of the crawl space in the area of the pumps had dropped to 95 °F, with an outside air temperature of 85 °F.

Interviews found that rooms 27 and 28 were always warm in the winter and hot in the summer. An analysis of the rooms found that the room temperatures were 79 °F and the floor temperatures were 96.5 °F. The air flow rate was measured at 150 cfm with a design of 230 cfm. Further investigation determined that the rooms were directly above the mechanical room, where uninsulated steam lines ran near the ceiling, and several other heat-producing items were present (a large domestic hot water tank, and steam/hot water convertor). The result of all of the heat generation was that the temperature of the air at the ceiling of the mechanical room, directly below Rooms 27 and 28, was 98.4 °F. The thermostat for the mechanical room exhaust fan was located midway up the wall next to the MZ AHU. Air leaking out of the mixed air section of the MZ AHU was blowing in the direction of the exhaust fan thermostat. The result was that the thermostat was highly unlikely to read the high air temperatures occurring across the room near the ceiling. The ceiling (floor) was made of concrete and had no insulation so heat conduction was occurring. The rooms directly across the hallway from Rooms 27 and 28 were at 78.5 °F but were comfortable and the floor temperature was only 80.4 °F.

Figure 34 shows a floor diagram of the building noting temperature readings in the crawl space near the floor and the location of steam leaks and pump vents.

The building floor also had 20 1 x 1-ft holes for passing tubes and other dental equipment lines through. These were not plugged and allowed a free flow of air.

The MZ system had many air balancing problems, mostly due to occupant tampering of the room air dampers. An analysis of the air flow in the building found the total air flow to be near the original design conditions. The total air flow of the multizone system was measured at 10619 cfm in the ducts and 10530 cfm coming out of the diffusers. The design was 11925 cfm, which gave a measured air flow of 11 percent low. Some air leaks were detected around the AHU--estimated to be around 300 cfm. Measurement of the duct air flow was done by pitot tube traverse. Measurement of the diffuser air flow was done by an air flow hood. The air balance survey results are shown in Appendix D.

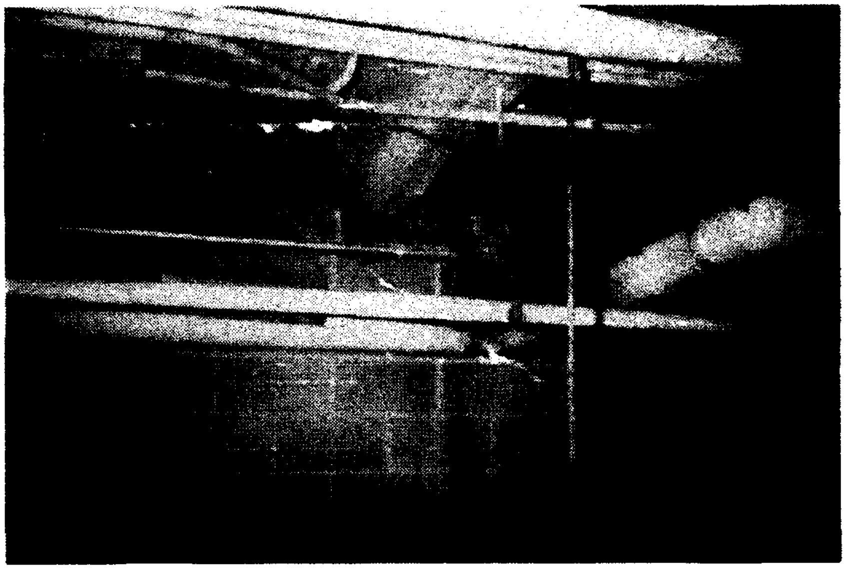


Figure 32. Location of Steam Leak in Crawl Space.

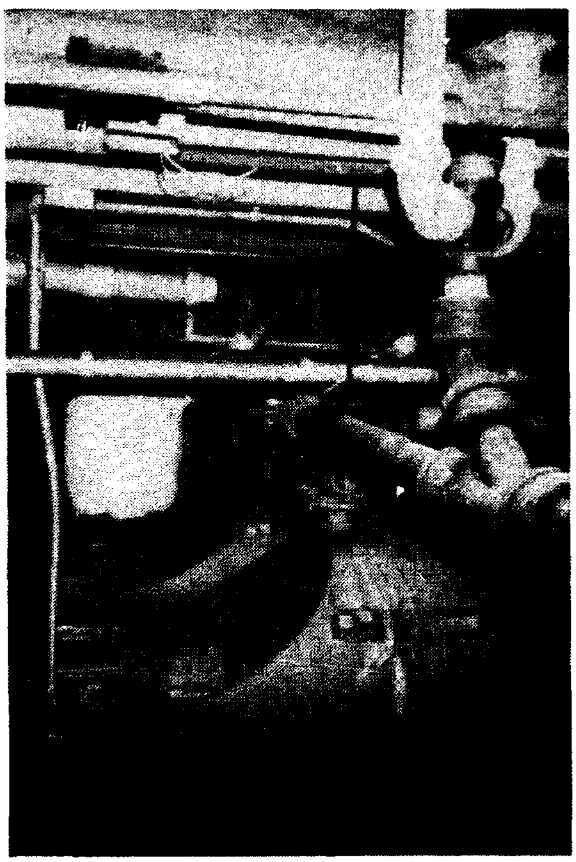


Figure 33. Vacuum Pumps.

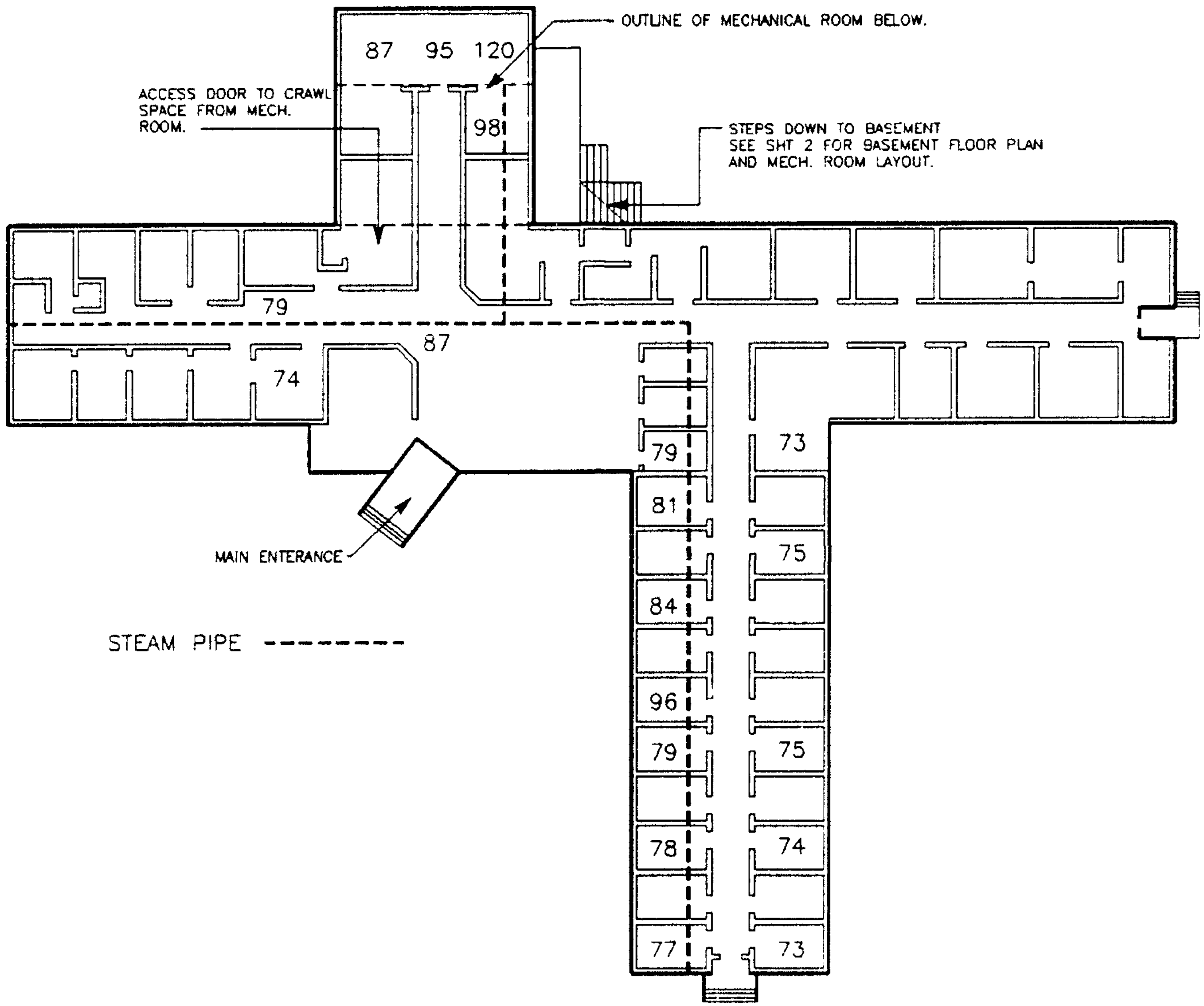


Figure 34. Crawl Space and Mechanical Room Temperatures.

The percentage of outside air used in the MZ AHU was measured and found to be approximately 29 percent. This was done by measuring the outside air temperature at the duct inlet, the return air temperature at the duct inlet, and the mixed air temperature, then using the following equation to determine the percent of outside air:

$$\%OA = \frac{(Tm - To)}{(Tr - To)} \qquad \text{[Eq 1]}$$

where

%OA	=	percentage of outside air
Tm	=	mixed air temperature
To	=	outside air temperature
Tr	=	return air temperature.

The analysis assumed that the humidity of the outside and return air are nearly the same, which was true at the time the measurements were taken.

The DEH personnel had informed researchers that the single-zone system had problems with maintaining space conditions during extreme temperatures so a panel in the outside air duct had been removed to bring in some air from the building. This air had been meant to be returned to the multizone system, so this action reduced the ability of the multizone system to heat and cool the air since it had to bring in more outside air.

The return air duct for the multizone unit had partially collapsed at some time. The cause was not determined, but it may have been due to opening of the single zone outside air duct as described above. During a brief time, the outside air damper to the multizone system had been closed because the MZ system could not maintain space temperatures. With the OA damper closed, and the SZ system taking air from the space that was meant for the MZ return air, the MZ system may have caused a large enough negative pressure in the return duct to collapse it.

A Building Load Analysis and System Thermodynamics (BLAST) computer study was done on the building and had determined that the HVAC systems, if operating according to the original design, would satisfactorily heat and cool the building.

USACERL researchers studied the effectiveness of the cooling coil in August 1989 to determine if the MZ system was able to cool the air according to original design conditions. The following equation was used to determine the coil effectiveness:

$$E = \frac{Thi - Tho}{Thi - Tci} \qquad \text{[Eq 2]}$$

where:

Thi	=	entering (mixed) air temperature (MAT)
Tho	=	exiting (cold deck) air temperature (CDT)
Tci	=	entering (supply) chilled water temperature.

By design, with a measured entering chilled water temperature of Tci = 46 °F, the effectiveness should have been:

$$E = \frac{82.3-55}{82.3-46} = 0.75$$

The zone damper positions were adjusted so that all of the MZ system air was flowing past the cooling coil. The outside air damper was closed and the following air temperatures were measured before and after the coil:

MAT = 72 °F wb and 80 °F db
CDT = 66 °F wb and 68 °F db

These values resulted in a coil effectiveness of:

$$E = \frac{80-68}{80-46} = 0.35$$

Next, the return air damper was closed and the following air temperatures were measured before and after the coil.

MAT = 72 °F wb and 85 °F db
CDT = 65 °F wb and 67 °F db

These values resulted in a coil effectiveness of:

$$E = \frac{85-67}{85-46} = 0.46$$

The following morning, the return air damper was closed and the following air temperatures were measured before and after the coil:

MAT = 70 °F wb and 75 °F db
SAT = 64 °F wb and 66 °F db

These values resulted in a coil effectiveness of:

$$E = \frac{75-66}{75-46} = 0.31$$

These results showed a very large deviation between the design and actual coil effectiveness, probably attributable to the HVAC systems inability to maintain temperatures in the building during extreme outside air temperatures. An interview with DEH personnel determined that the water circulated through the MZ system was never treated. This probably caused the coil tubes and system piping to become scaled with mineral deposits that decreased piping and coil efficiencies.

To help alleviate some of the cooling problems, the steam to the building could be shut off in the summer and the domestic hot water could be changed to gas-fired instead of steam. It was recommended for the location of the thermostat for the mechanical room exhaust fan to be changed to better remove the heat in the room. Air flow could be increased in rooms 27 and 28 to help alleviate the uncomfortable conditions in those rooms. It is doubtful that the heating coil would be able to achieve setpoint when the OAT was below 30 °F with 28 percent outside air. An attempt should be made to clean or replace the coils so that they could better transfer heat.

The thermostat for Zone # 1 was located in the Supply Room—not a good location since it was unoccupied and not indicative of the temperature of the whole zone. A better location would be in one of the Exam Rooms. The thermostat for Zone # 4 was located in an office that, on the original design, was part of the open administrative area. This was probably a good location for the thermostat in the original design but is no longer indicative of the zone and should be moved to the Waiting Area.

The holes in the operating rooms should be plugged to reduce infiltration. The building could be better insulated, especially the floors, to save energy and increase the comfort level of rooms. The maintenance of the building and HVAC system could be improved to save energy and provide better space conditions. Not only do the leaking valves and uninsulated pipes waste energy, but they cause an increase in energy consumption to cool the spaces where the leaks occur. Fans were brought in to increase air movement to cool Rooms 27 and 28, increasing energy costs and adding the cost of the fan purchase. The new heat pump for the Prosthetic Lab may not have been needed if the vacuum pumps had been exhausting outside instead of into the crawl space where significant amounts of heat were added to the prosthetic lab load. Following the energy survey, a meeting was held with Fort Campbell DEH personnel to report the findings.

Development of the HVAC Control System Design Package

The DEH Engineering Plans and Services Branch (EPS) assigned to the project an engineer who had experience with designing HVAC control systems. Since the designer had no previous knowledge of the standard HVAC control systems, USACERL researchers displayed a standard HVAC control panel and reviewed the CEGS and TM with the design engineer. The designer then proceeded with the design of the control system.

A few questions arose, but in general the designer had no problems with putting together a design package. The design package included collecting general project information, bidders information, a bidders list, general scope of work, specifications on work to be done other than the standard control system, the specifications from CEGS 15950, and design drawings.

Contracting Process

The contract for the control system went out as an Invitation For Bid (IFB), not a Request For Proposal (RFP), so no design review of contractor work was to be done before award of the project. Only one bid, by a local contractor, was received by the contracting office. Originally the bid was very high, but after discussions with the bidder, a new lower bid was made. The project was so small that many of the solicited bidders declined to bid, and other small companies were so unfamiliar with the technology that they were uncomfortable bidding on the project.

Description of the HVAC Control System

Figures 35, 36, 37, 38, 39, and 40 show several views of a typical standard HVAC control panel. The size of the panel has been reduced to a 30x24x16-in. NEMA 12 type enclosure. All tubing and wiring is to enter the panel through holes in the bottom of the panel to help prevent the possibility of water getting into the panel. Louvers are incorporated into the rear of the panel for ventilation to help keep the temperature in the panel from rising to a point where it could damage equipment. The other views show other panel and door dimensions, as well as standard locations for devices and terminals. The standard panel now can accommodate six controllers, although special panels with up to eight controllers can be built. The specific function of a controller in the first slot might change, but its location and set of wiring terminations would remain the same. Each standard control system would have standard locations for specific controllers, devices, and wiring terminations. The pilot lights and panel switches were specified as rectangular and each standard control system would have standard locations for its lights and switches. The inner door was to have a continuous hinge as shown and would have the rail-mounted I/Ps located on the back side as shown. The relays would be located along the top of the back panel, and the relay sockets would be rail mountable. In general, all panel devices would be rail mountable as shown. This was to help ease replacement and interchangeability of devices. The terminal strips would be located as shown and wiring trays were to be used. Function modules, power supplies, and the time clock would be located along bottom row. Most of the features of field devices remained the same and many of the features of panel-mounted devices remained the same also. All control signals to and from devices were still specified as 4 to 20 mA or 3 to 15 psig. Further information concerning the specifications and designs of the standard HVAC control systems are contained in CEGS 15950 and TM 5-815-3.

For Fort Campbell the decision was made to install new control systems on the MZ unit and the convertor so that the results of the retrofit could be better tracked. The option was available to control both the MZ unit and the convertor using one control panel, by placing all seven controllers in one panel. Because an eight-controller panel had not yet been constructed, it was decided not to test this version, especially since the contractor was unlikely to be familiar with the standard panel concepts. In addition, electric zone damper actuators and zone thermostats would replace the old pneumatic devices. The convertor valve, hot deck valve and the cold deck valve would also be replaced with new valves with positive positioners. The existing pneumatic actuator for the dampers was to be retrofitted with a positive positioner.

The design called for two control panels to be used, one to control the multizone AHU and one to control the converter. The convertor control panel was to have two controllers and was designed to be slightly smaller than the standard panel, as provided for in the CEGS design at the time. It was later determined that a standard sized panel could have been used since the price of the smaller panel was about the same. Figures 41, 42, and 43 detail the convertor control panel. Figures 44, 45, and 46 show a system schematic and ladder diagrams for the convertor system.

The control panel for the multizone AHU required the use of five controllers. Figures 47, 48, and 49 detail the MZ unit control panel. Figures 50, 51, and 52 show a system schematic and ladder diagrams for the multizone system.

Submittal Review

The contractor submittals covering equipment data and shop drawings were reviewed and approved by Fort Campbell personnel. USACERL researchers also reviewed the submittals and did not find any major problems with the equipment data sheets and shop drawings. The contractor had some difficulty

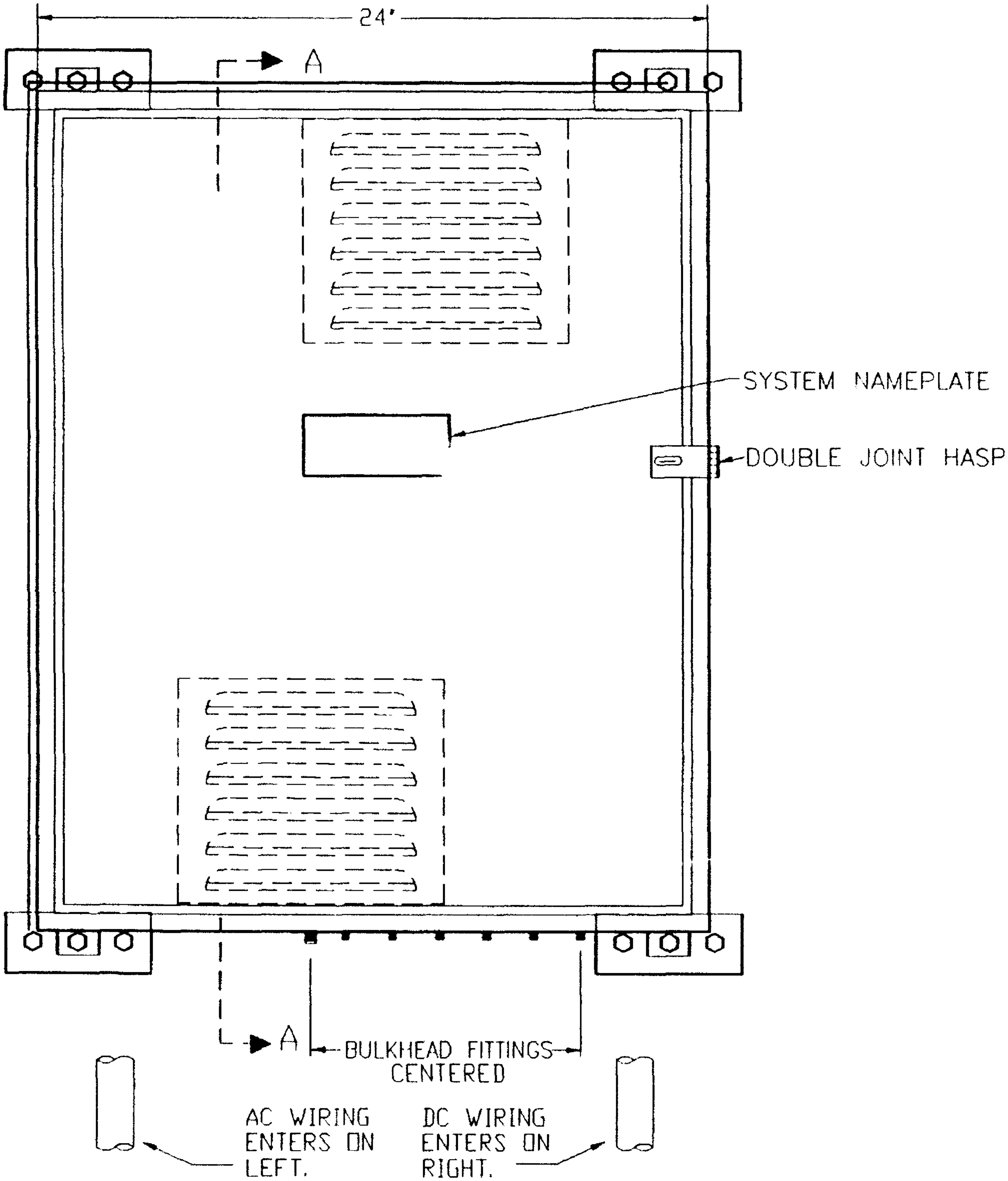


Figure 35. Standard HVAC Control Panel—Front View.

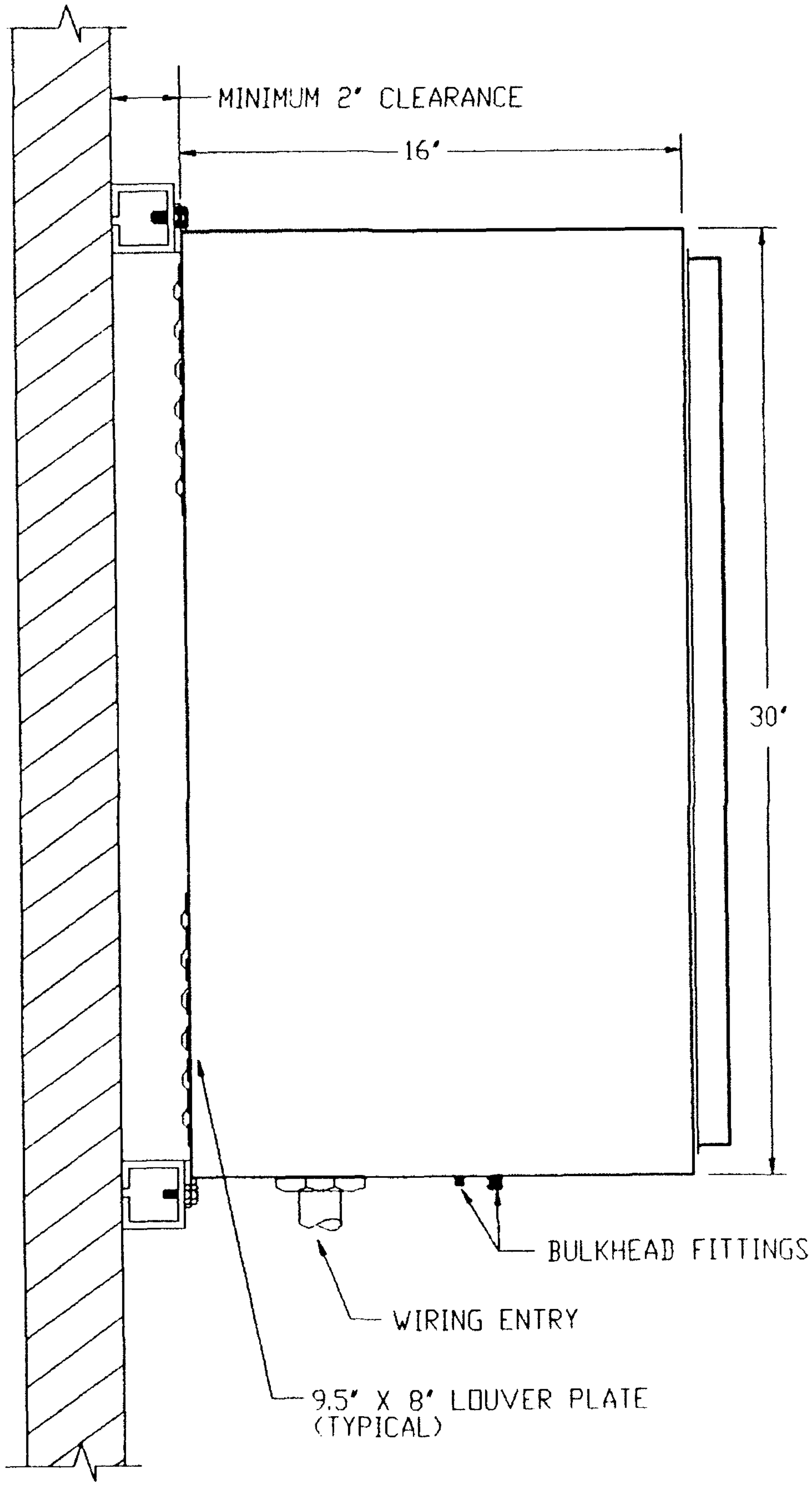


Figure 36. Standard HVAC Control Panel–Side View.

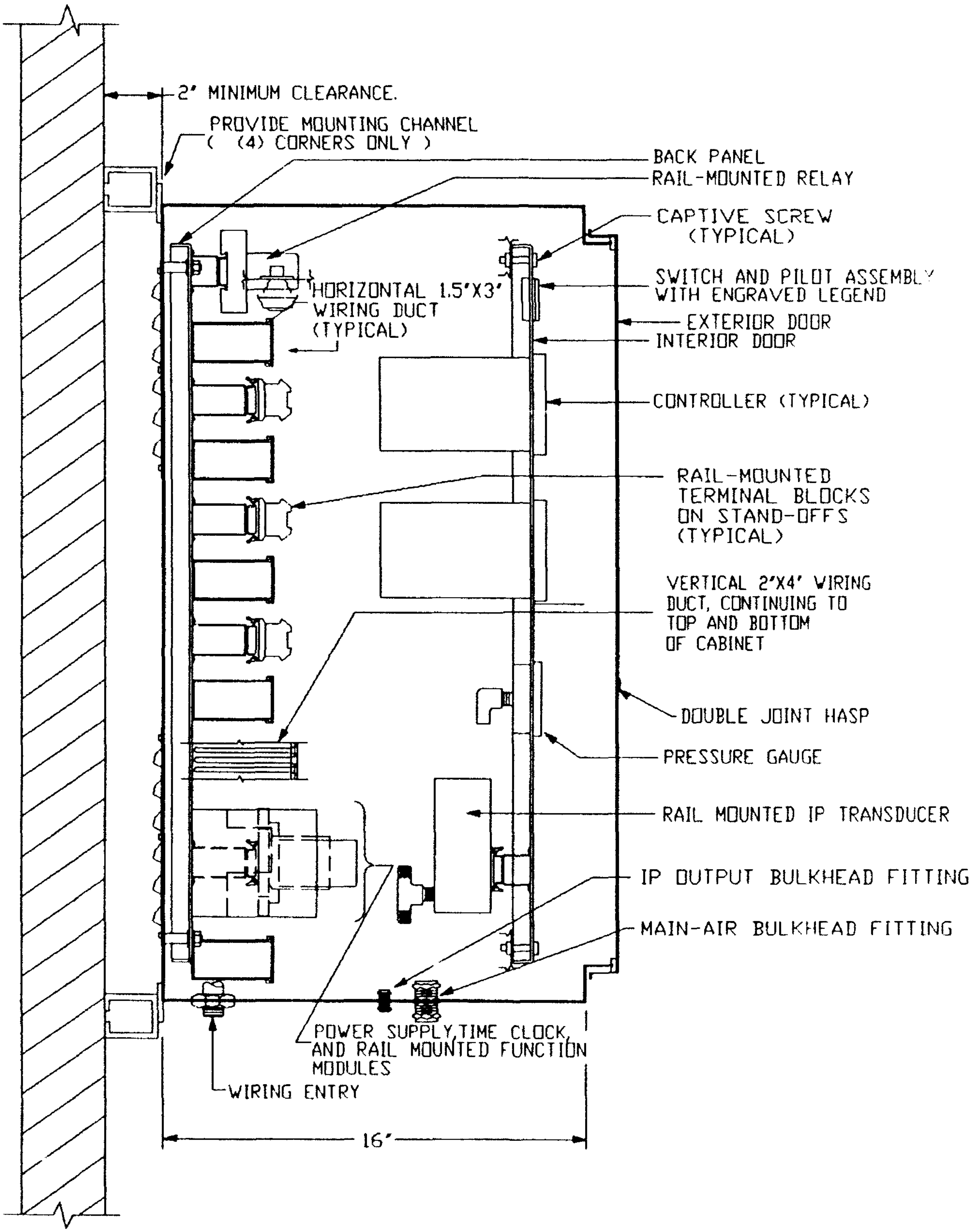


Figure 37. Standard HVAC Control Panel—Section A-A.

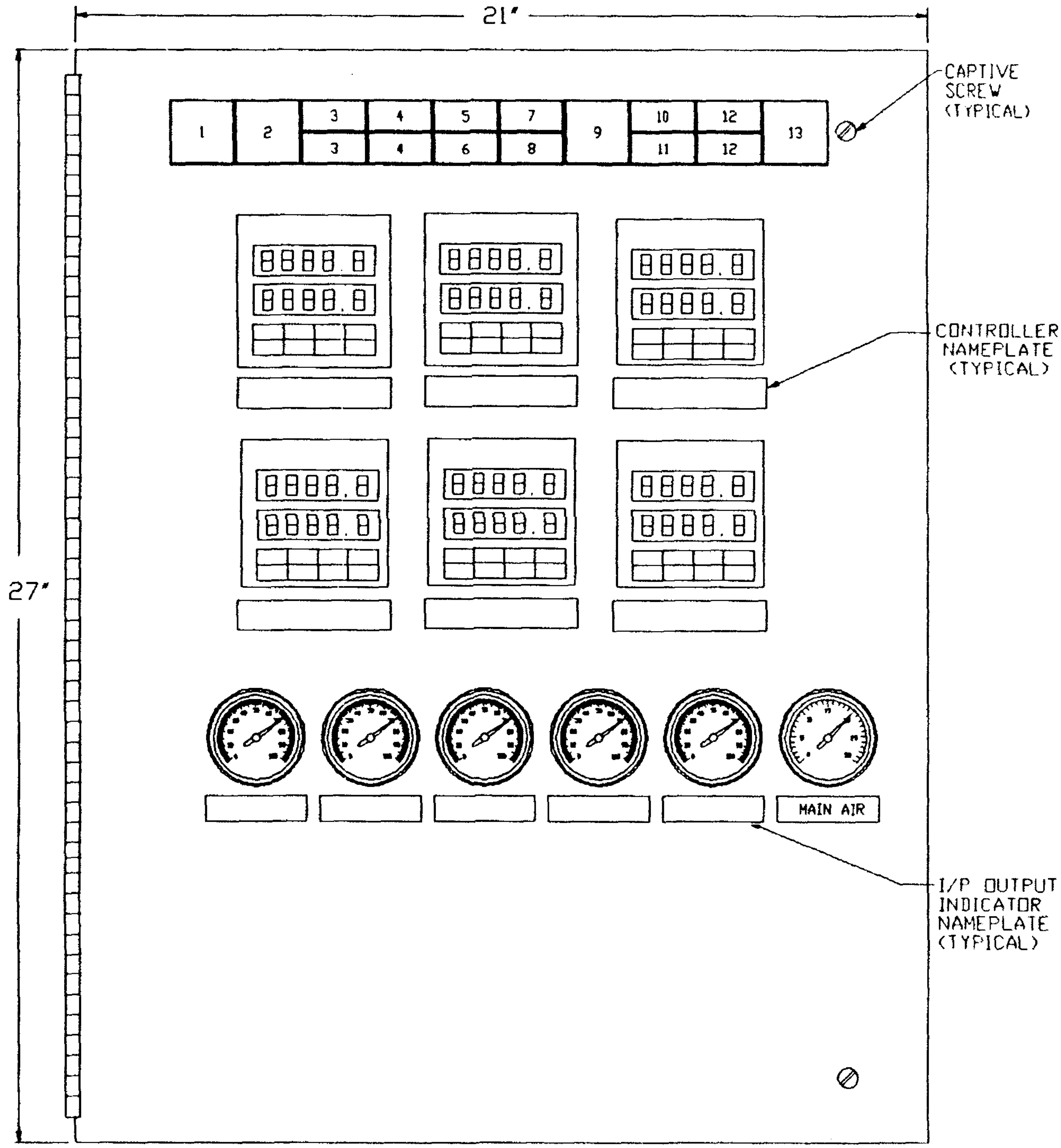


Figure 38. Interior Door Layout–Front View.

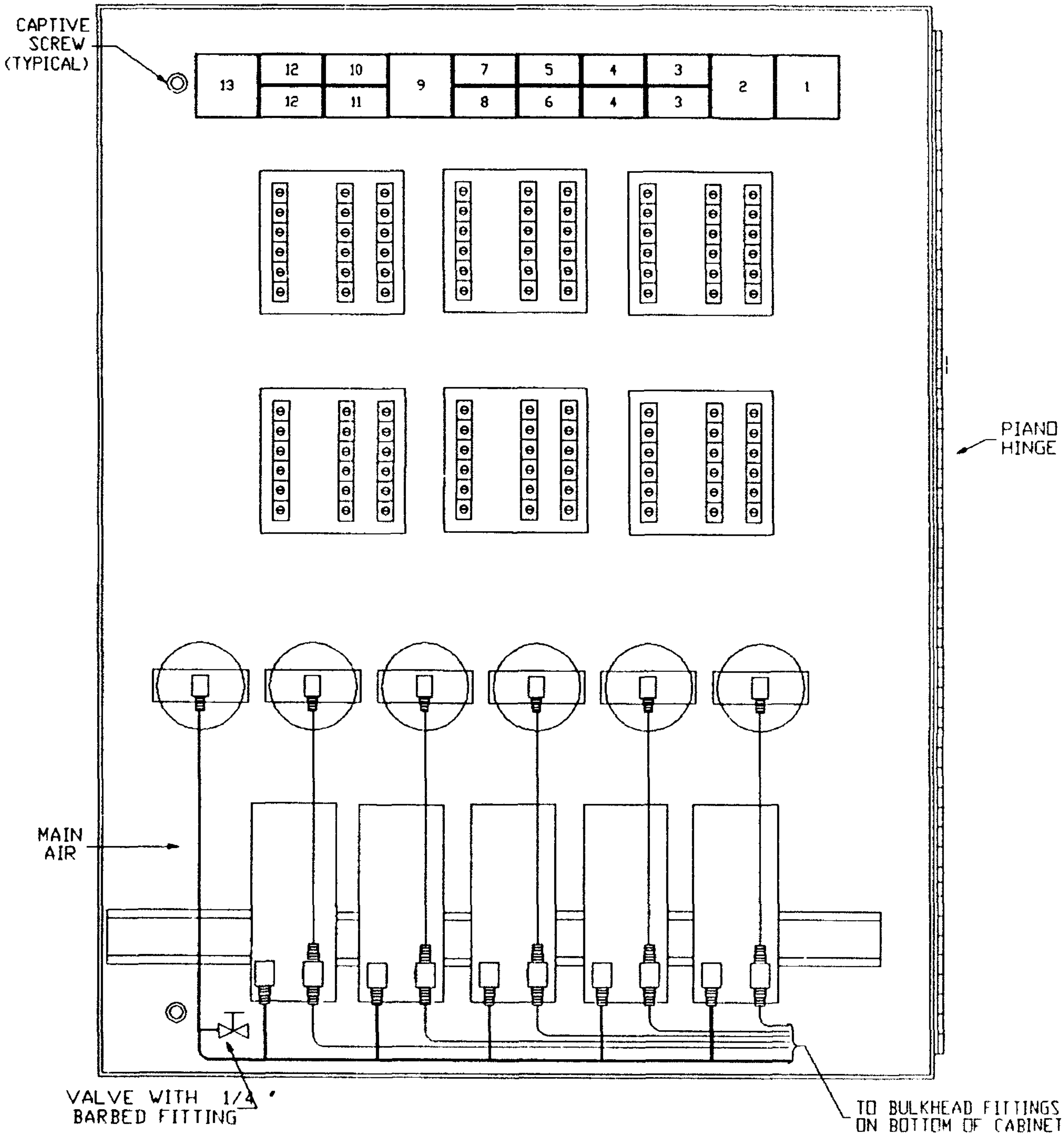


Figure 39. Interior Door Layout–Rear View.

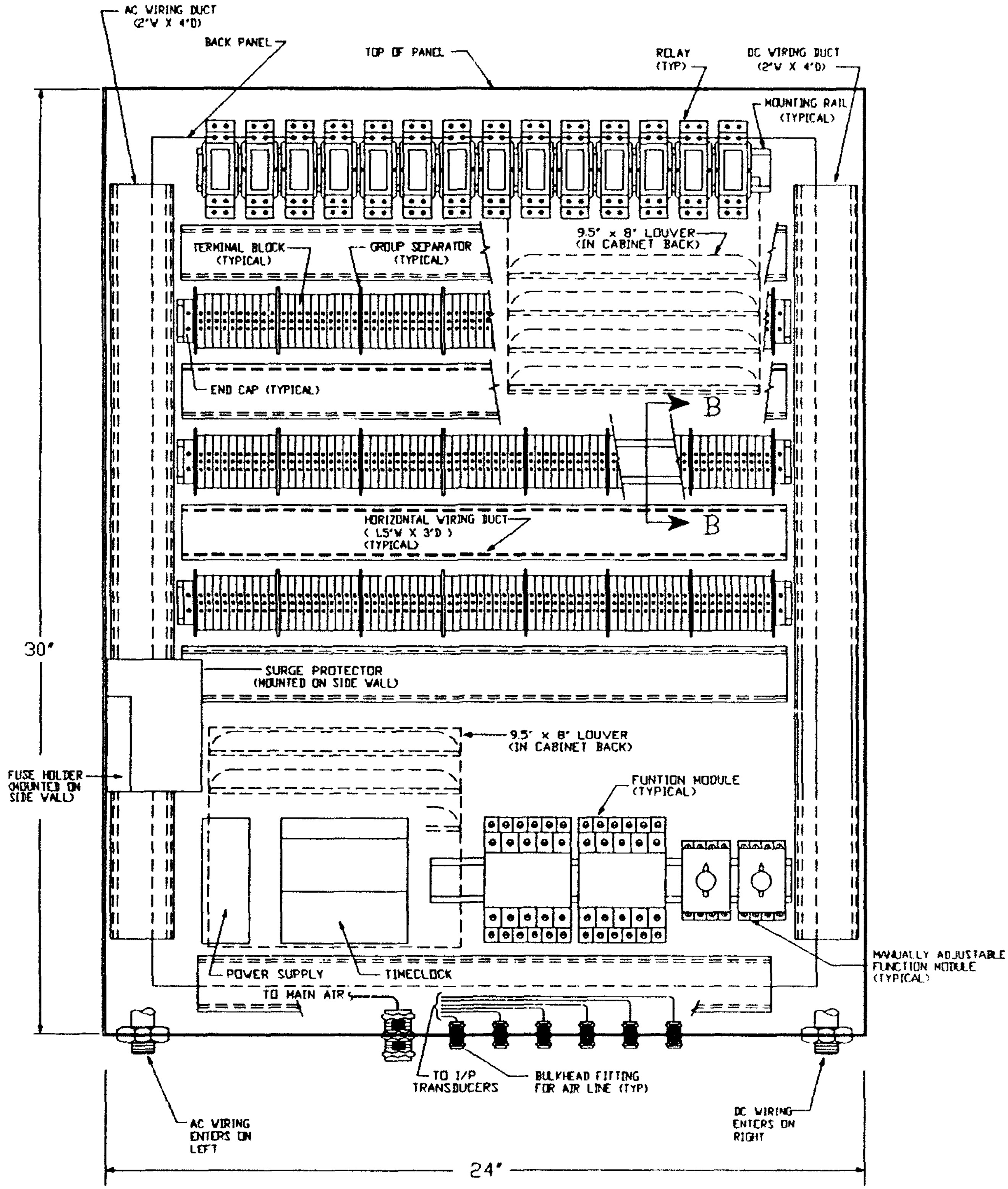
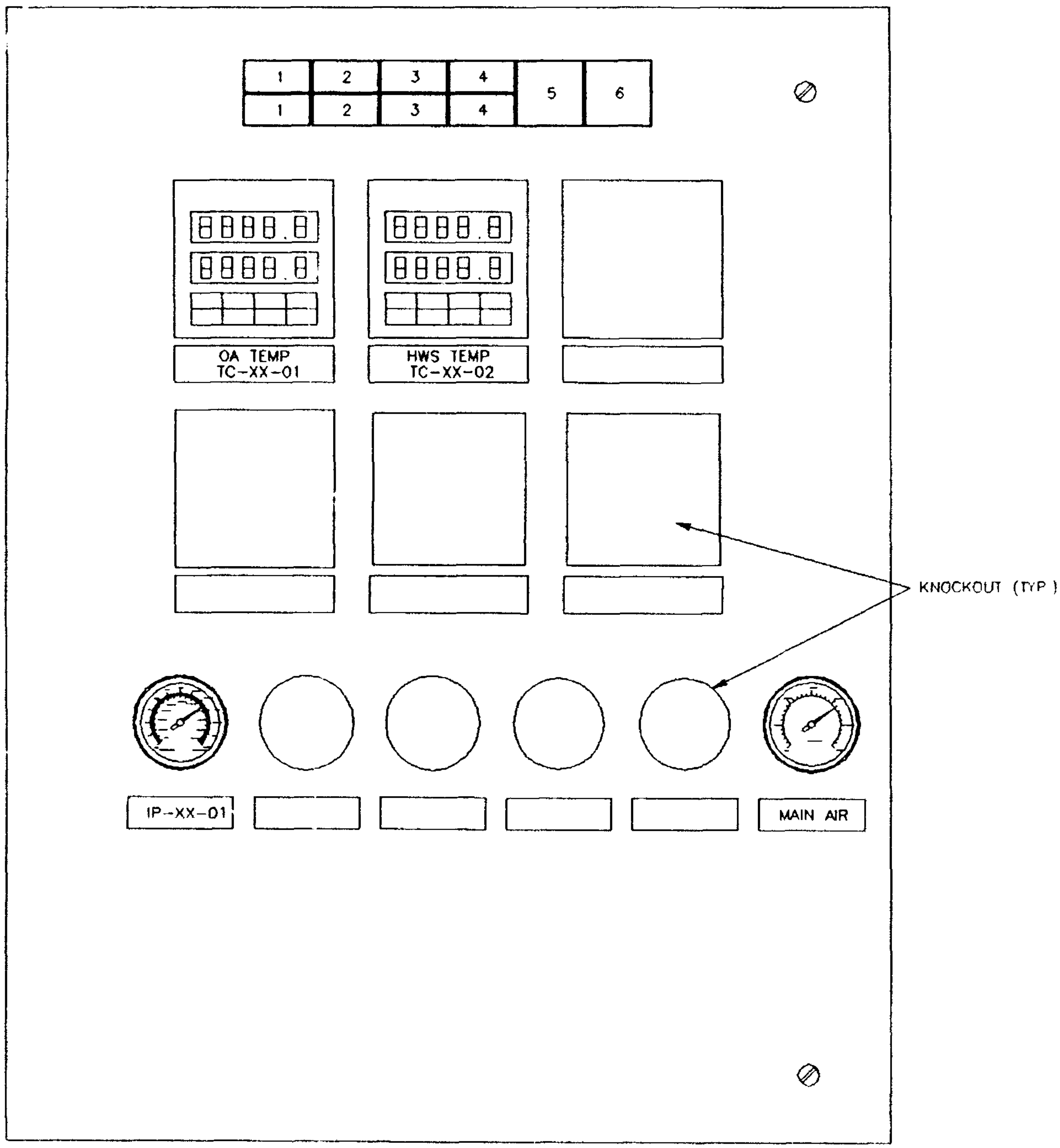


Figure 40. Back Panel Layout.



(FRONT VIEW)

Figure 41. Convertor Control Panel Inner Door Layout–Front View.

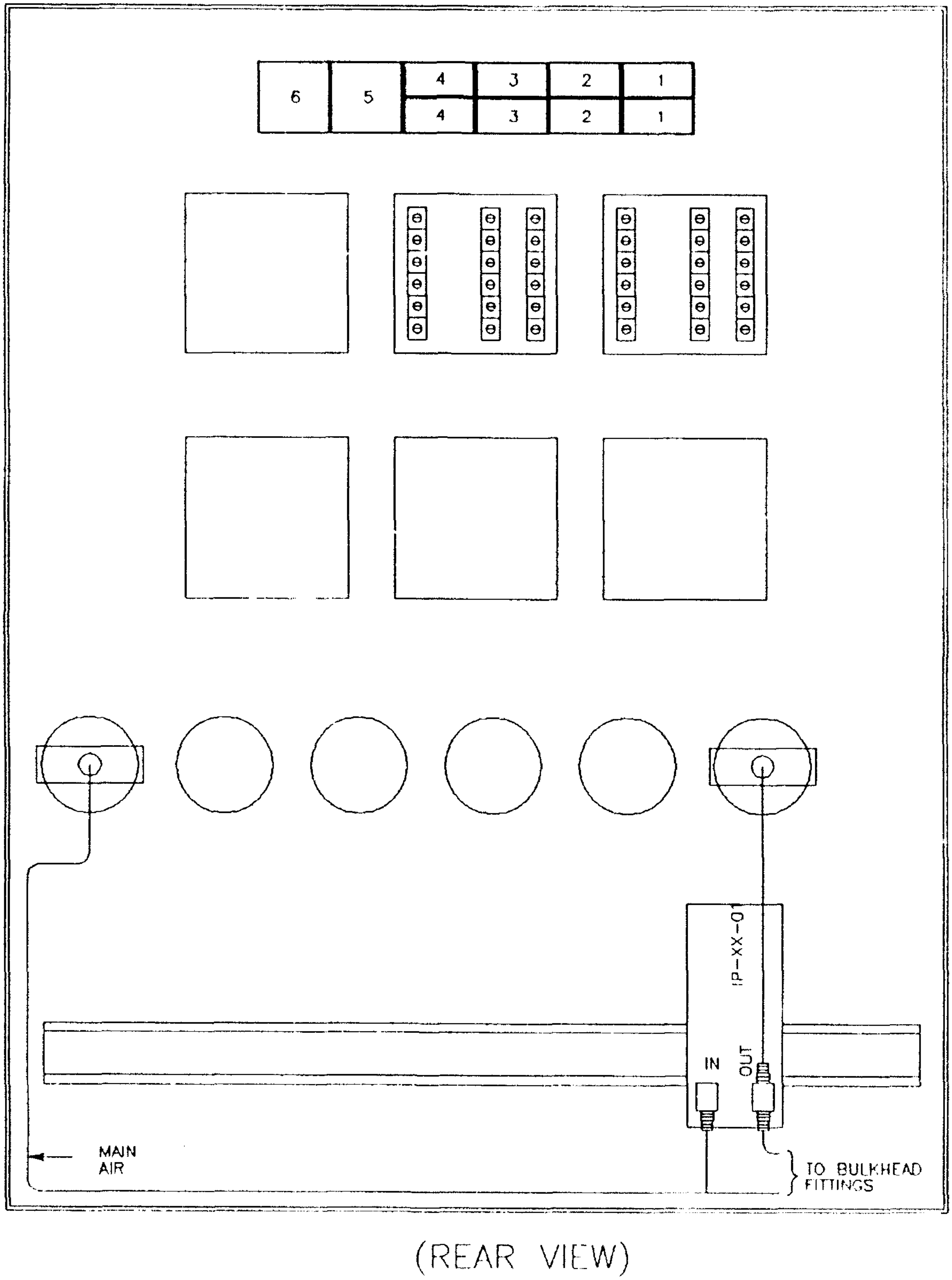


Figure 42. Convertor Control Panel Inner Door Layout–Rear View.

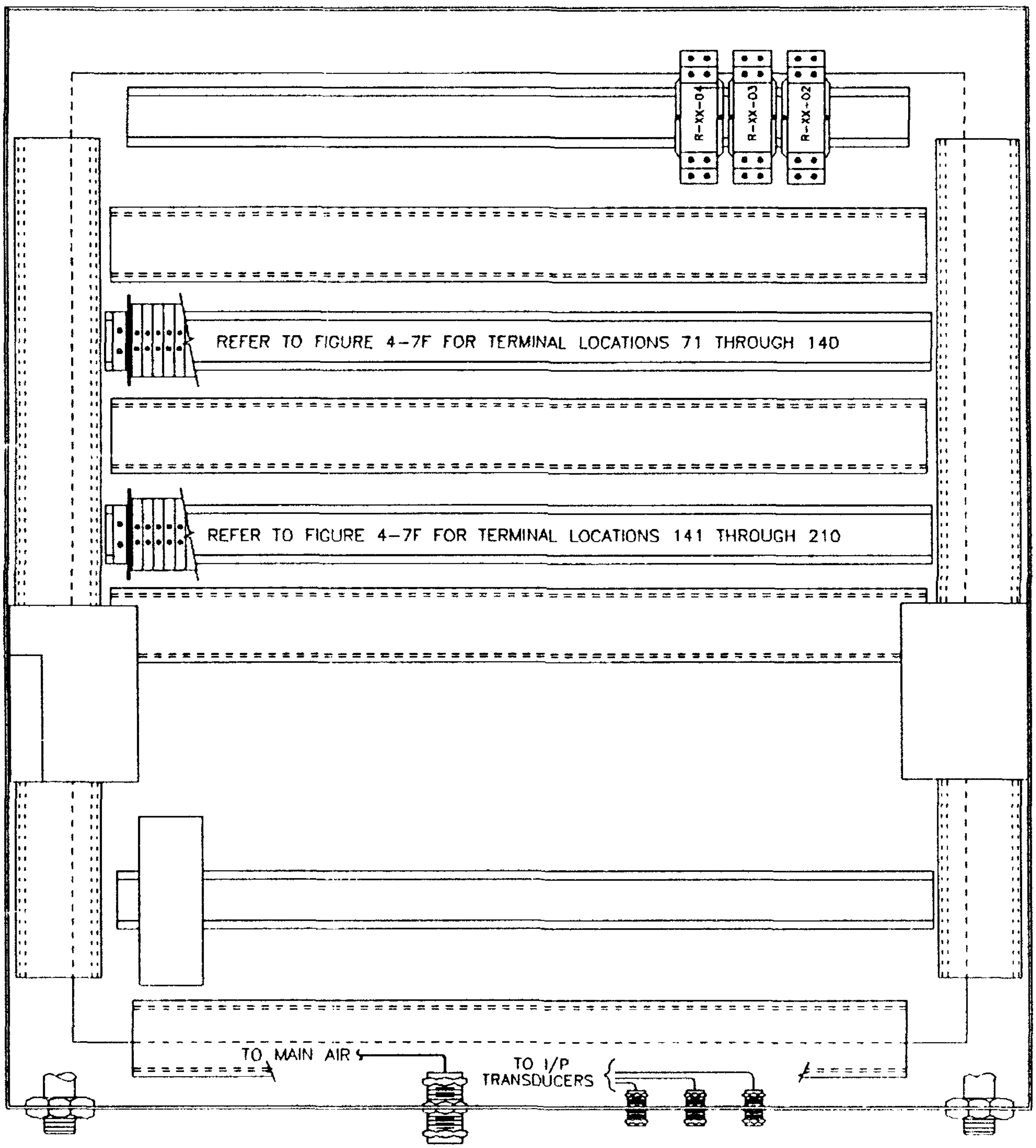


Figure 43. Convertor Control Panel Back Plate Layout.

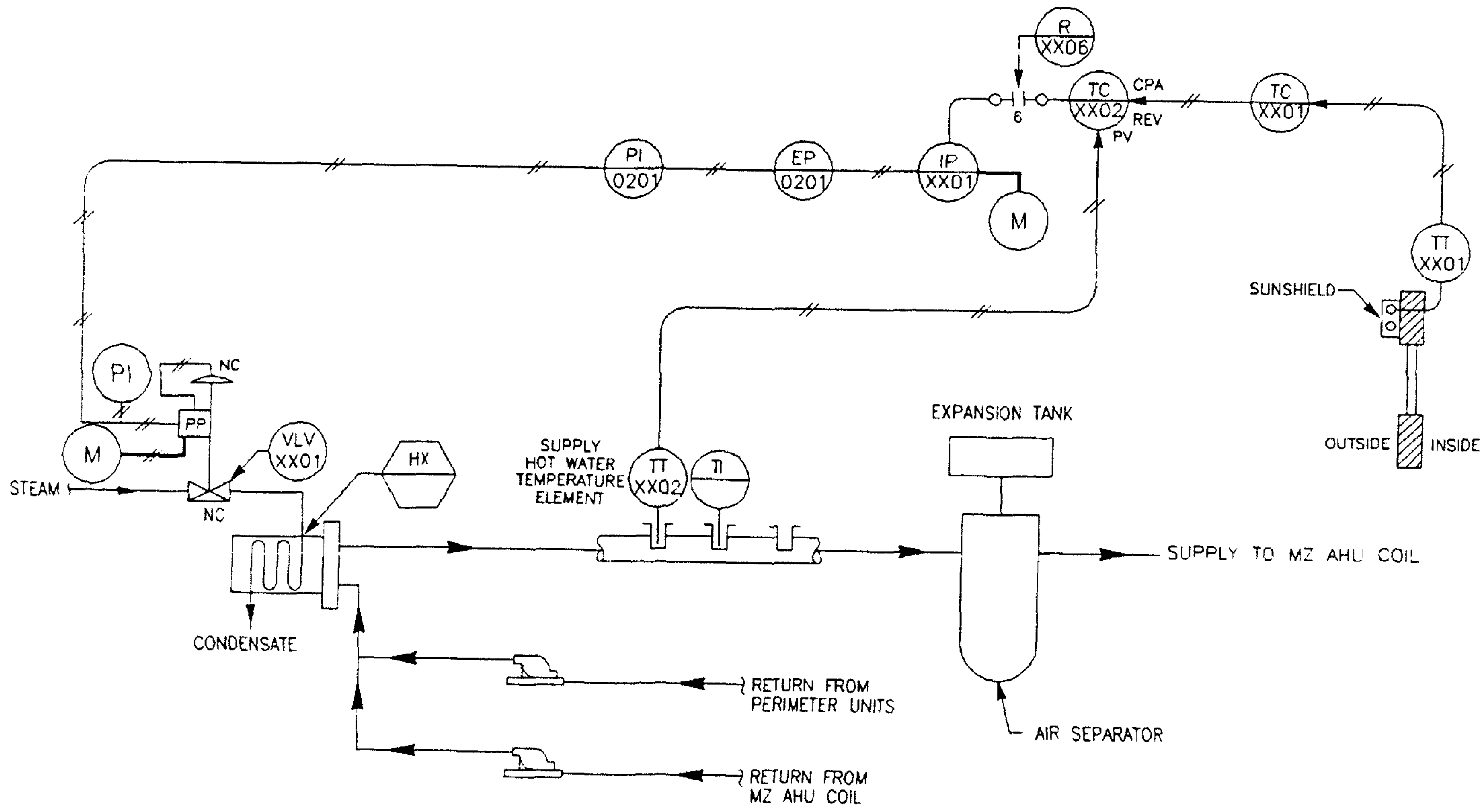


Figure 44. Schematic View of New Control for Convertor System.

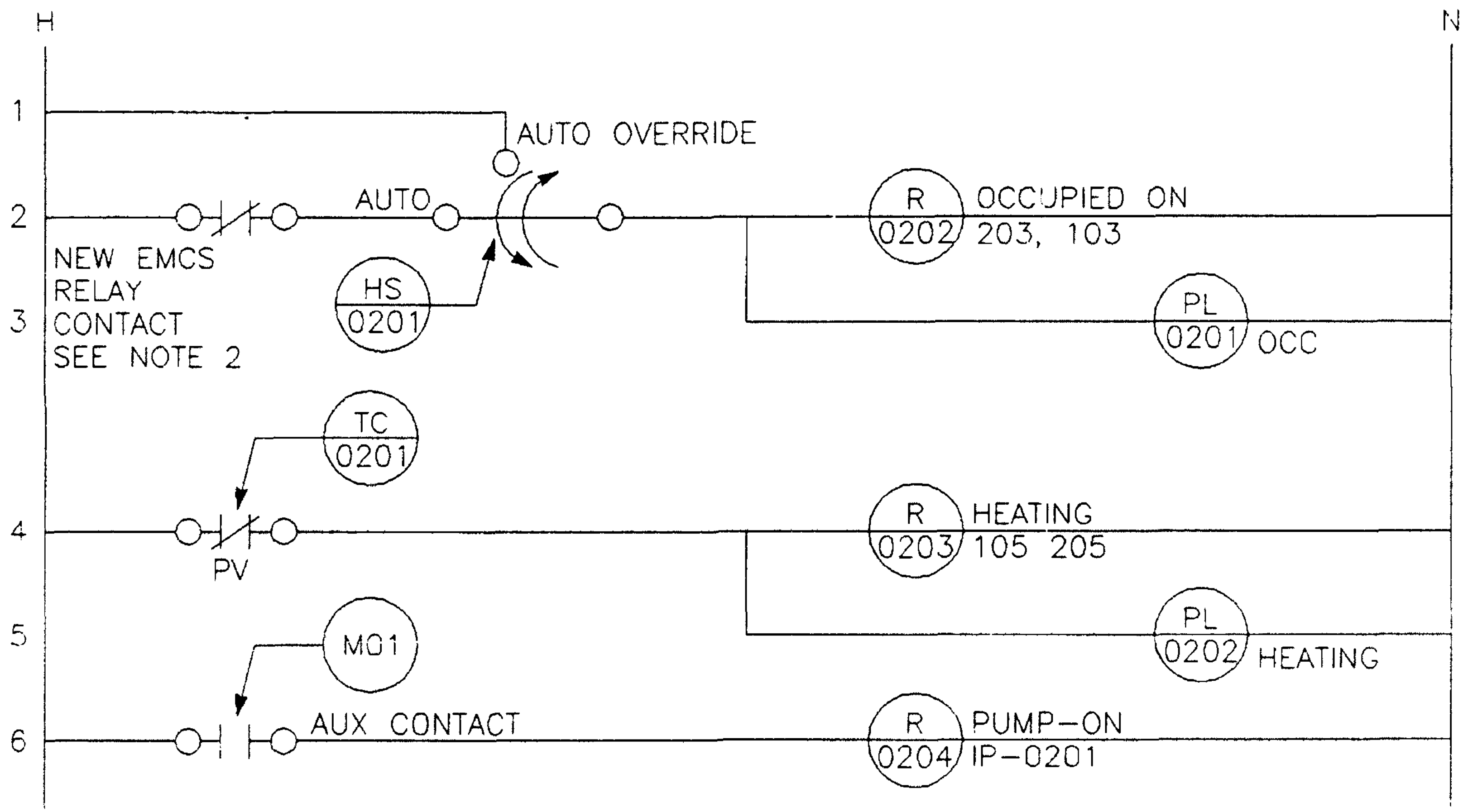


Figure 45. Ladder Diagram for Convertor System.

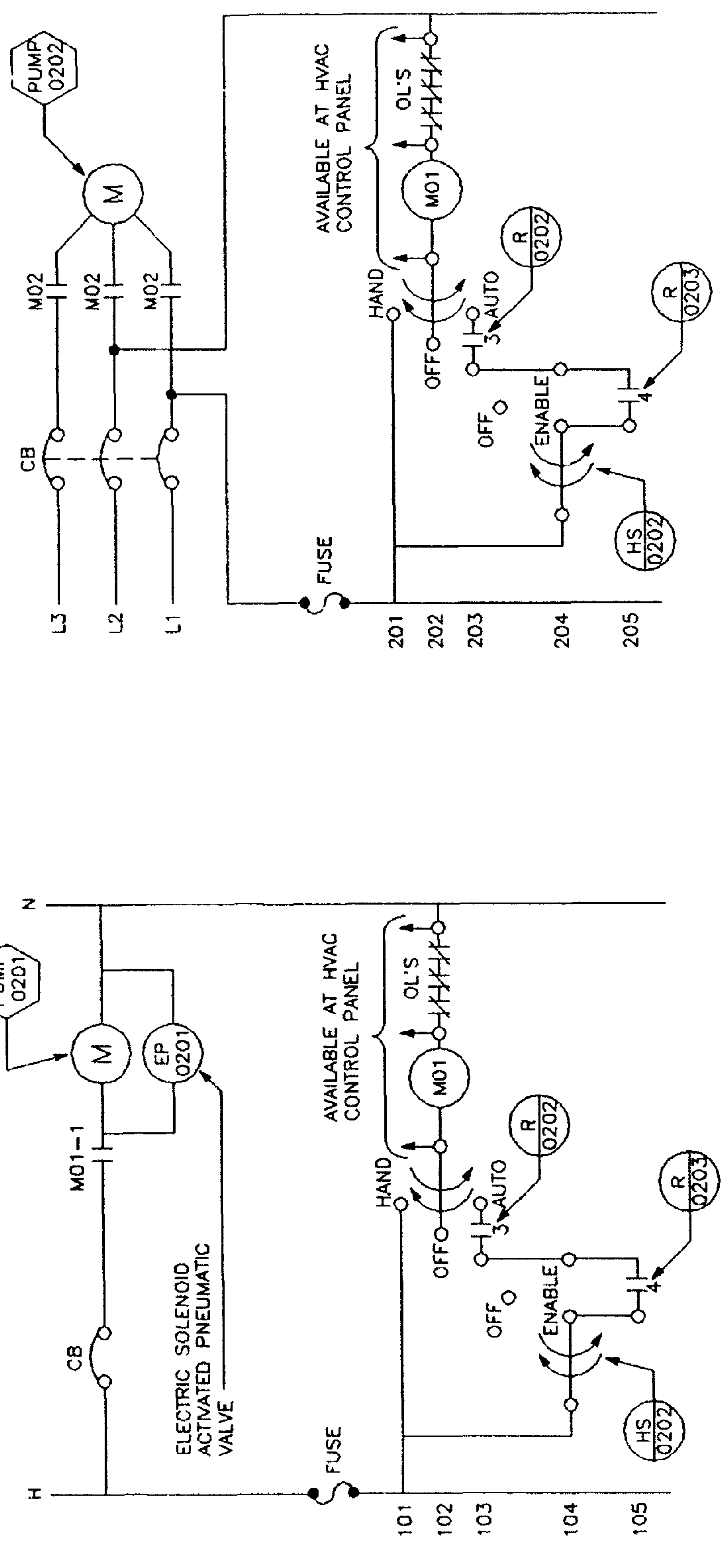


Figure 46. Motor Starter Ladder Diagram for Convertor System Pumps.

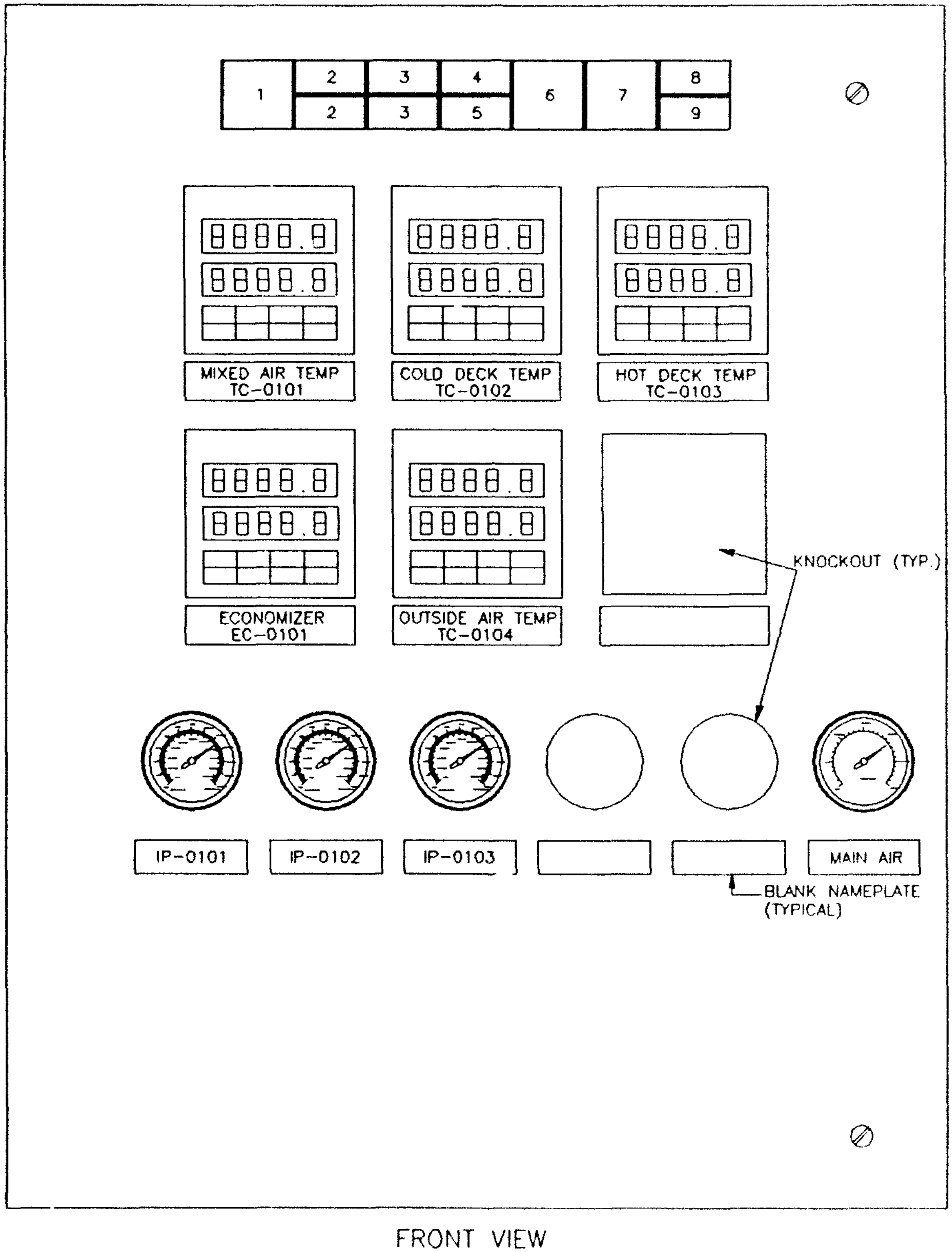


Figure 47. Multizone Control Panel Inner Door—Front View.

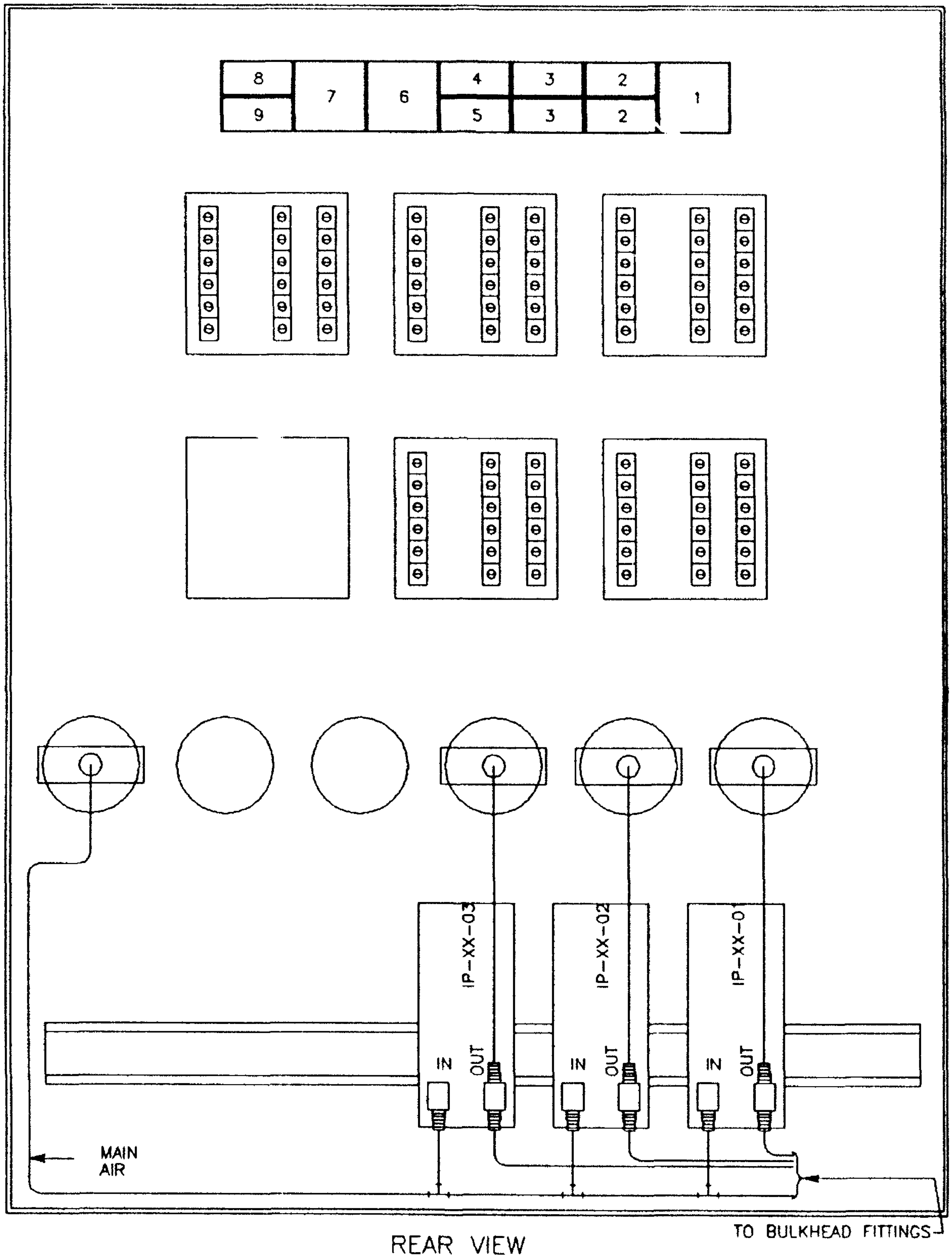


Figure 48. Multizone Control Panel Inner Door–Rear View.

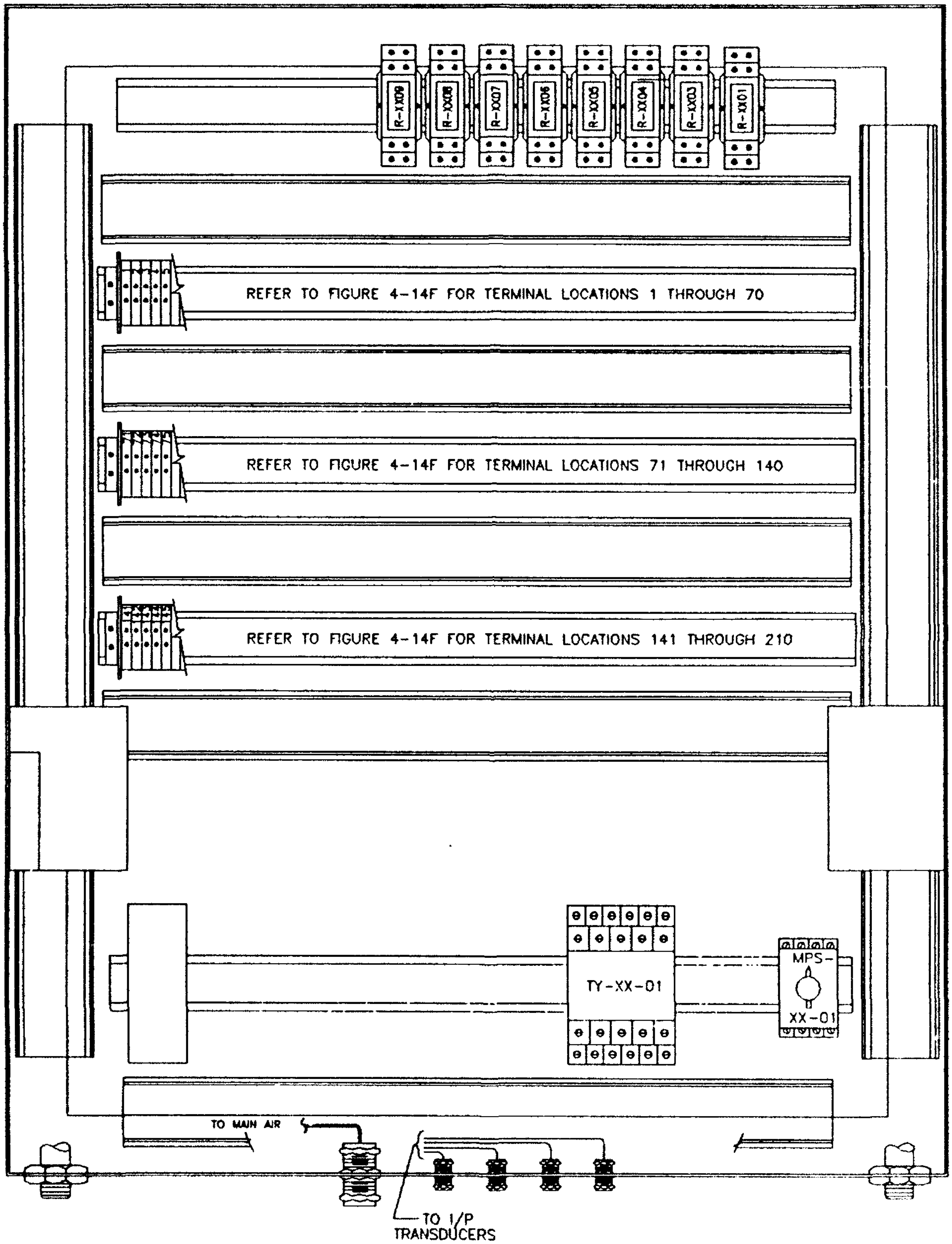


Figure 49. Multizone Control Panel Back Plate.

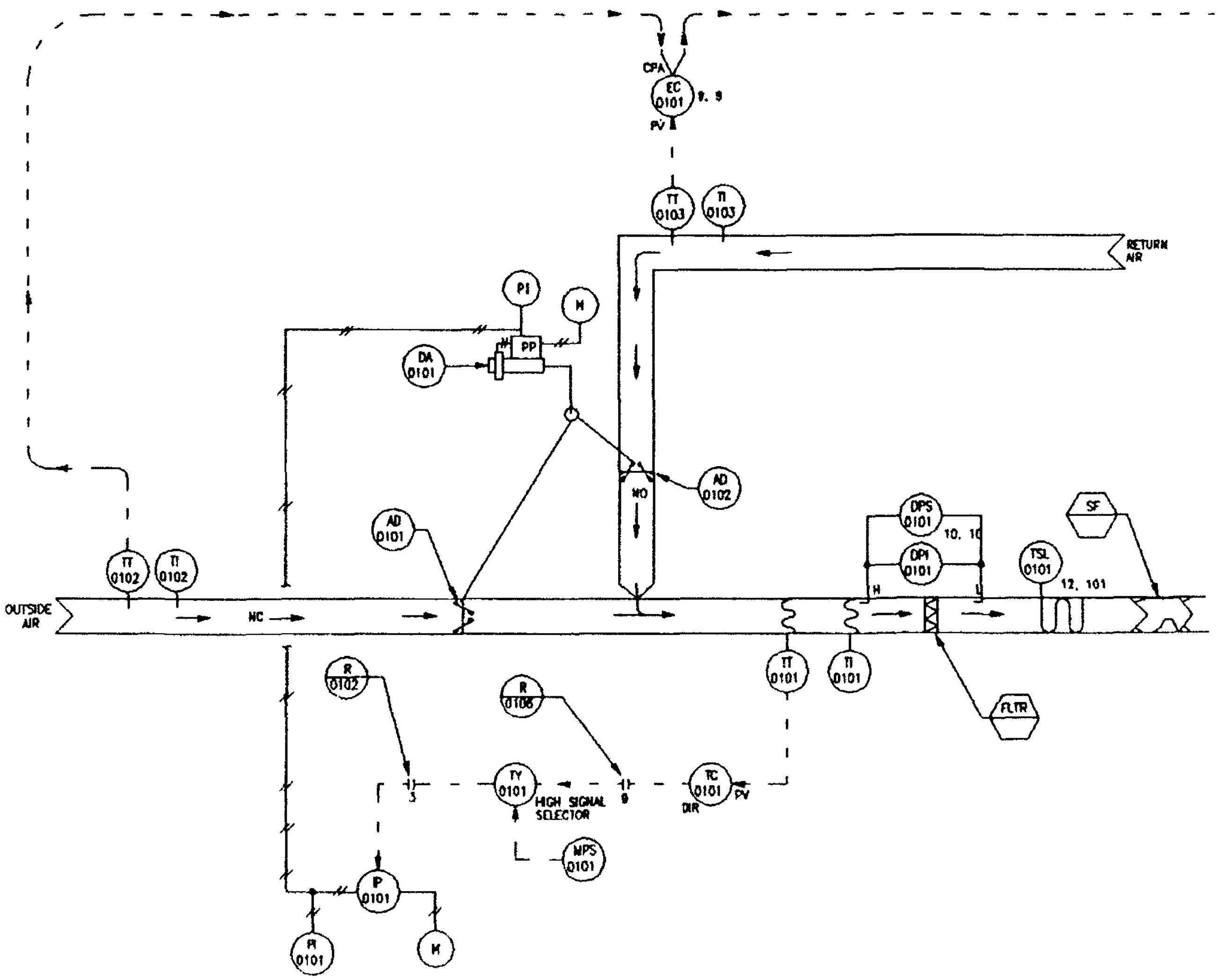


Figure 50. Schematic View of Multizone Control.

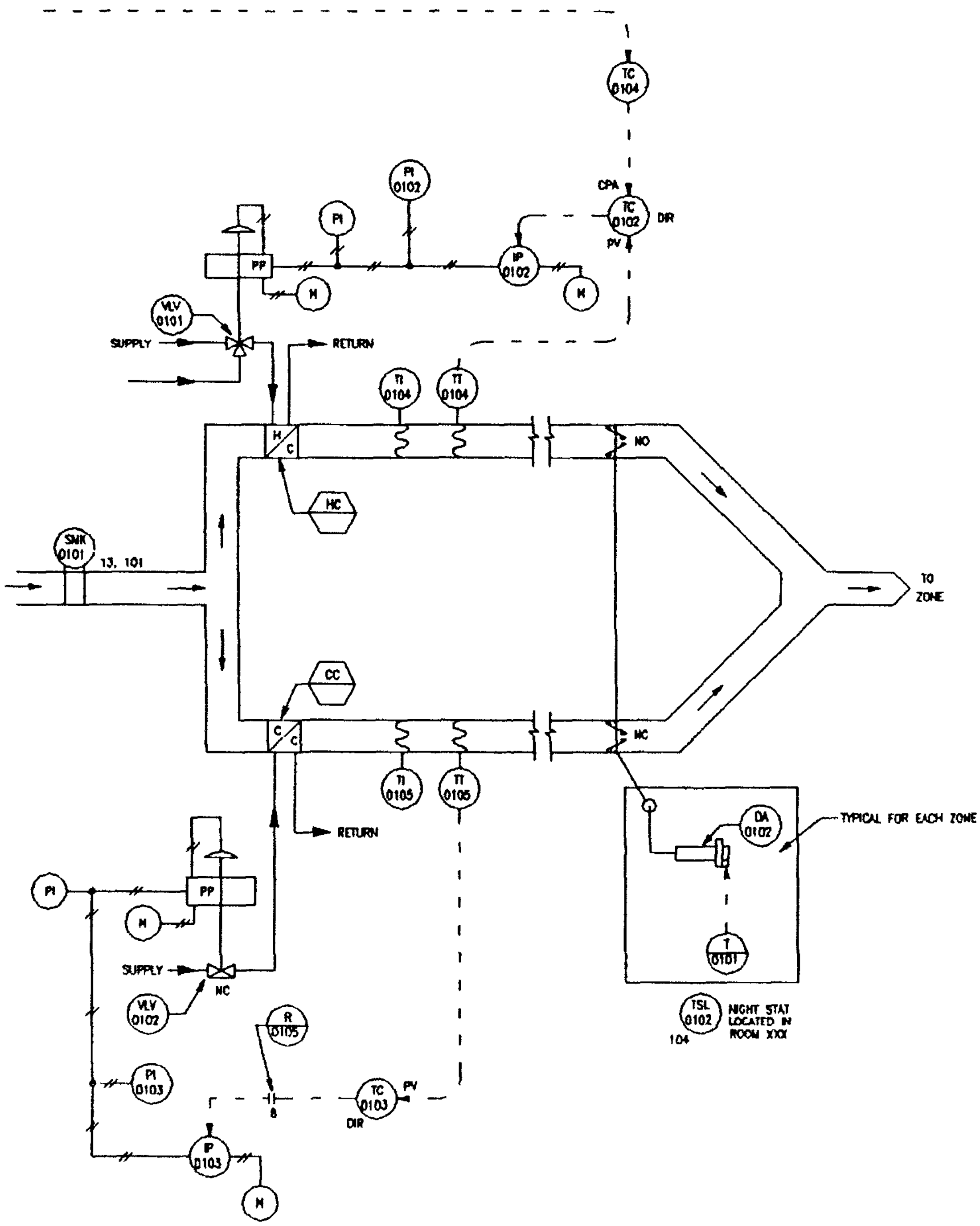


Figure 50. (Cont'd).

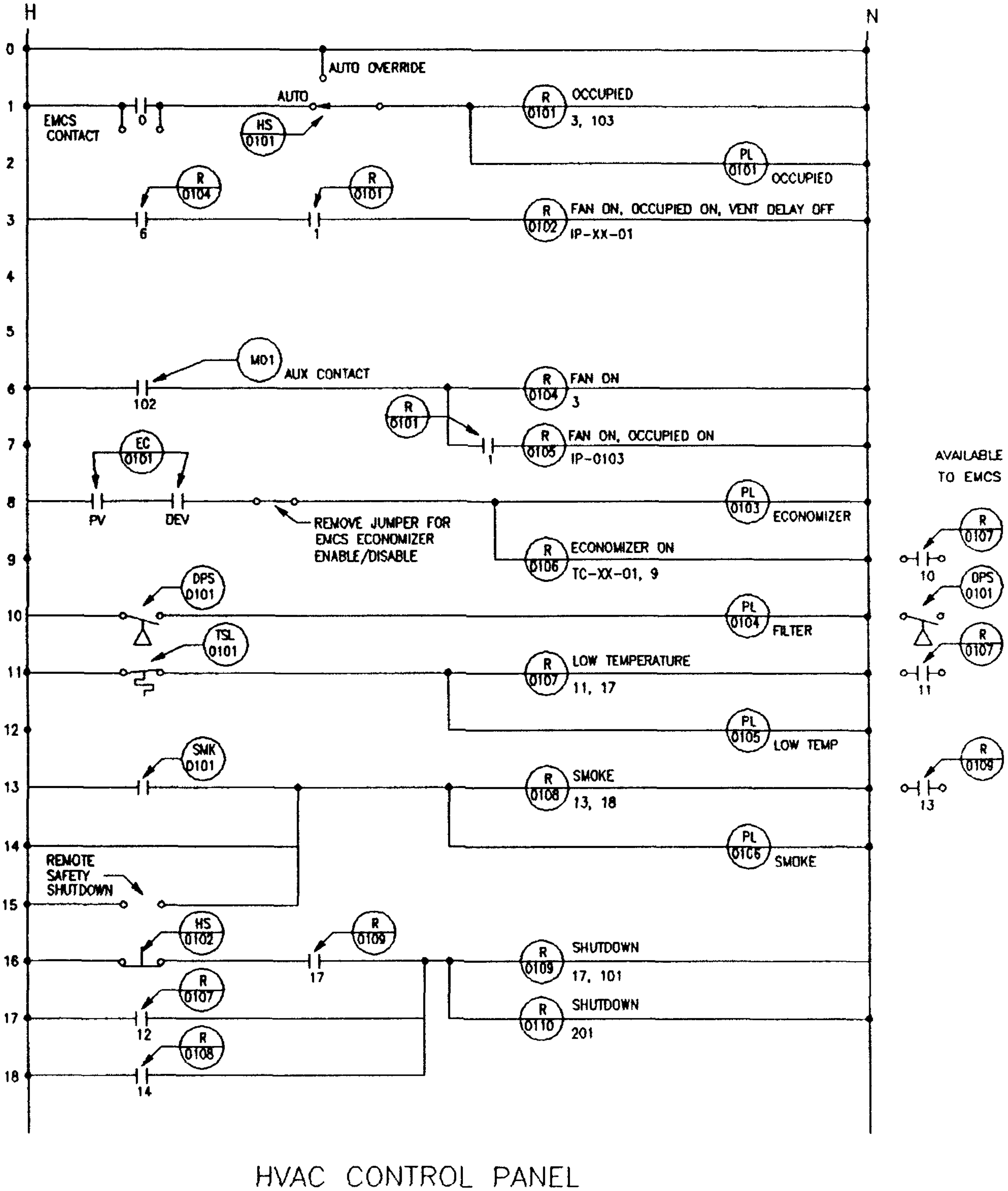
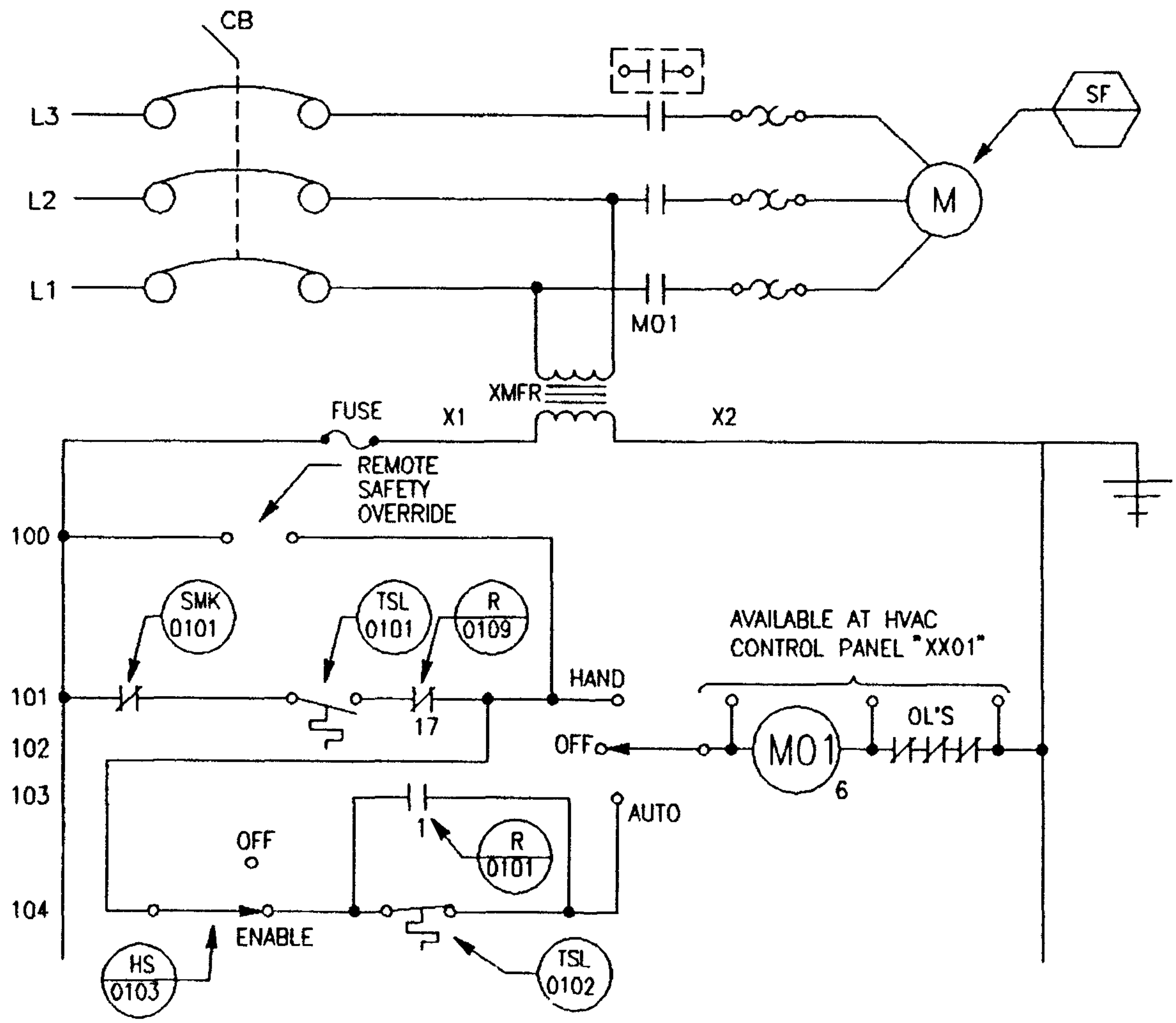


Figure 51. Multizone Ladder Diagram.



SUPPLY–FAN STARTER

Figure 52. Motor Starter Ladder Diagram for Multizone Fan.

interpreting the CEGS or finding devices that met the specifications. Following are some of the issues that arose during the review of the equipment data sheets and shop drawings.

It was noted that the equipment data sheet for the current-to-pneumatic (I/P) transducers did not indicate that the output was field selectable or that the transducer was rail mountable as per the specifications. These issues were missed during the initial review and resulted in installation of a lower quality device that subsequently failed.

The contractor did not submit an equipment data sheet for the minimum position switch and stated that they had some problems locating a minimum position switch. They asked if they could build a device using a transmitter and potentiometer, and USACERL approved the idea, but also gave the contractor the names of several manufacturers that offered the switches. The contractor resolved the issue by using one of the manufactured devices.

Researchers also noted that the equipment data sheets for the panel switches did not indicate that they were interlocking types as per the specifications. The contractor had trouble finding switches that met all of the specifications. Again, USACERL researchers had to send them information. Later, the contractor had to be informed that the bulkhead fittings for the pneumatic connections had to be tube-to-tube type. The contractor had not submitted a catalog data sheet for the positive (pilot) positioners. During construction of the panel, the contractor required assistance. The contractor had to be informed that the wiring trays were typically connected to the back plate, not to the side wall. The contractor also wanted to move the relays to a different position but USACERL instructed them to follow the design.

The contractor minimally met the intention of the CEGS concerning the operation and maintenance manuals. In addition, the contractor did not follow the CEGS procedures by rewriting the sequences of operation included in the O&M Manual, nor did the contractor follow the format of the commissioning procedures in the CEGS, or prepare good performance verification test procedures.

Installation and Commissioning of the Control System

The contractor did not have any problems during installation of the control panel (tat phase of the project went smoothly). The contractor was somewhat unsure about what the commissioning process was to accomplish. USACERL researchers explained that the commissioning of the system was to ensure that the contractor had the system calibrated, tuned, and operating correctly before the Government came to accept the system during the PVT.

Scheduling constraints of the project did not allow for good timing of the flow of documents. The short schedule of the contract allowed little time to send documents out for review and acceptance. As a result, paperwork errors that occurred during the commissioning process were not discovered until the performance verification test. This was not a problem since researchers were evaluating the contractor's ability to interpret the CEGS. Figure 53 shows the panel as installed in the mechanical room.

Acceptance and Performance Verification of the Control System

The contractor was also unsure of the PVT's objectives. Researchers discussed the objectives of the PVT with the contractor and reviewed the contractor-generated PVT Procedures. PVT procedures were found to be generally lacking in detail. USACERL researchers had anticipated this and had developed PVT procedures for an MZ system for use at Fort Campbell.

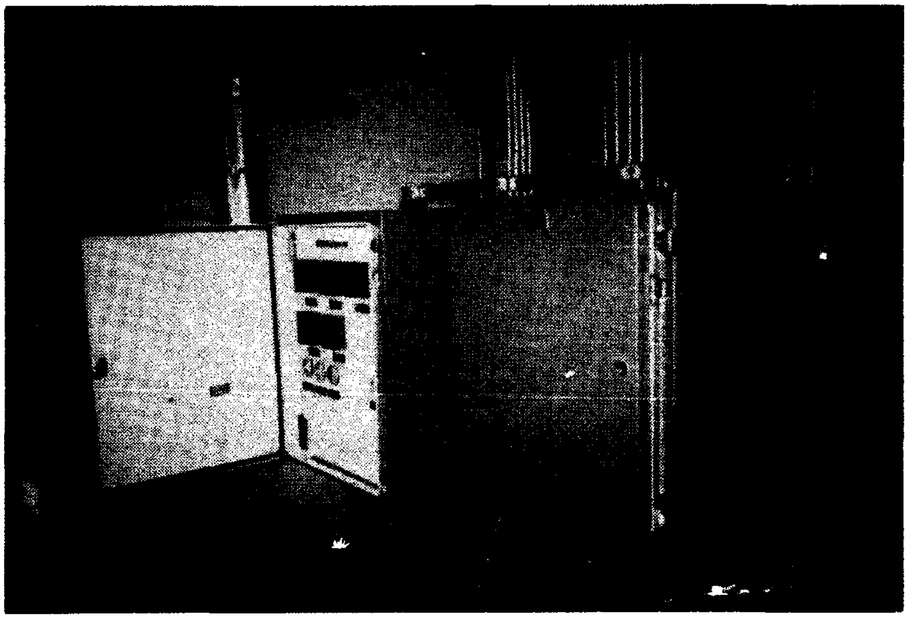


Figure 53. Motor Starter Ladder Diagram for Multizone Fan.

USACERL personnel, base personnel, and other Corps representatives attended the performance verification test (PVT) conducted by the contractor in May 1990. The test revealed that the contractor had misinterpreted the intent and process for doing reset of the hot water temperature according to the outside air temperature. This had to be corrected during the PVT. The contractor had set up the minimum outside air incorrectly and this was discovered during the PVT. The contractor had interpreted that a 28 percent outside air setting meant that the output of the minimum position switch should be 28 percent of the actuation signal (8 mA). This setting resulted in an almost 50 percent minimum outside air since the flow through dampers is generally not linear. This was corrected during the PVT.

Training of Operation and Maintenance Personnel

Following a successful completion of the PVT, the contractor held a training course that was attended by Fort Campbell personnel. The agenda of the Training Course is included in Appendix E.

Connection of the HVAC Control System to EMCS

The EMCS provides the timed function of occupied and unoccupied ventilation as would normally be provided by the time clock. For this reason the time clock was not used and the EMCS was interfaced with the control panel as shown in the ladder diagrams. The EMCS's existing temperature sensors monitor temperatures in the building.

Evaluation of the Standard HVAC System Performance

The I/Ps that the contractor used in the construction of this panel are commercial grade "off the shelf" products. Fort Campbell HVAC Technicians have had to replace three of the four original I/Ps in the first 2 years of operation. Fort Campbell personnel replaced all of the original I/Ps with industrial grade products, as intended in the CEGS. To date, these are operating reliably. Besides the I/P, the control system has been operating accurately and reliably. Setpoints are being maintained and sensing accuracy remains within specifications.

6 LESSONS LEARNED DURING THE FORT CAMPBELL DEMONSTRATION PHASE

A retrofit user guide concerning design and procurement at the DEH level is needed. This would include retrofit design information, information concerning the overall scheduling, the various checklists mentioned, and other general information.

A predesign site survey, maybe as part of a retrofit user guide, is needed to help the designer identify control components that can and cannot be reused, faulty control components that should be replaced, and HVAC and building problems, which if faulty, would affect the ability of the HVAC system to properly heat and cool the building.

There are five opportunities to review and check a control system being installed to confirm that it is correct: (1) during the Submittal Review stage; (2) at the factory test; (3) when the control system is being installed; (4) during commissioning; and (5) during the PVT.

A few mistakes were made during the design stage that could have been avoided if a design checklist was developed. The TM at the time failed to mention that the wiring diagrams shown in the TM should also be included as part of the design package. The omission was noted and the TM now mentions the wiring diagrams. The design checklist could help make sure that small, yet important, details are not forgotten when preparing a design package. The contractor was given a copy of the wiring diagram, which was carefully followed even though it was not legally required.

Trying to keep track of all the submittals and requirements of submittals that the contractor is to deliver is not a straightforward process. A submittal review checksheet could help streamline the review process and make sure that important details are not overlooked.

Reviewing the contractor-submitted equipment data sheets to confirm that the CEGS requirements and specifications have been met was found to be time-consuming and not straightforward. The typical review process involves comparing the submittals with the CEGS. Since the CEGS is a contract-type document, the specifications for a specific item are not always all in one place. This makes the checking-off process somewhat difficult. Some component requirements can thus be missed in the review process. In addition, the equipment data sheets for some components may not be submitted and this could go unnoticed. Equipment inspection checklists are needed to streamline the review process and make sure that details are not overlooked. Such a checklist probably would have brought the wrong current-to-pneumatic transducer that the contractor was planning to use immediately to the researchers' attention.

The commissioning procedures in the CEGS and the specifications stated about the commissioning procedures and report leave some openings for interpretations that could lead to mistakes. More detailed commissioning procedures should be developed and tighter requirements should be incorporated into the CEGS.

More information needs to be stated in the CEGS about the requirements of the performance verification test procedures and report. The CEGS leave some openings for interpretations and deviations that could cause problems.

Acceptance of the control system by the contracting branch personnel of the DEH may often be a problem. Most contracting branch people have little knowledge of HVAC systems and controls and cannot judge whether the system works correctly or as designed. DEHs must ensure that the design engineer and maintenance technicians get involved with the review and acceptance processes.

The contractor prepared minimally acceptable operation and maintenance manuals. At one point the contractor said that since the project was costing more than expected, they were not going to give anymore than the minimum. For example, the CEGS said that the O&M Manuals should be submitted in booklet form, but said nothing about the binding for the booklets. The contractor thus submitted manuals on 8 1/2 × 11-in. sheet in a folder rather than a hard binder as intended. This met the letter but not the intent of the CEGS.

The 4-day Training Course specified in the CEGS is too long for the information that needs to be dispersed. (Only a 2-day course is required.) A 4-day course raises the total cost of the control systems without adding significant information. Moreover, it is also doubtful that an installation would want to unnecessarily dedicate their staff to the 4-day course.

7 CONCLUSIONS AND RECOMMENDATIONS

This demonstration successfully tested and evaluated the standard HVAC single-loop digital control system concepts, designs, and hardware. It is concluded that standard single-loop control systems work accurately and reliably in the field. The control panel at Fort Leonard Wood has operated over 4 years, and the panel at Fort Campbell over 2 years, with no failures or required adjustments. Other control devices have operated efficiently and reliably, with little or no drift in accuracy and only a few failures. New specifications have ruled out those devices that did fail.

It was shown that interconnection of the control systems with EMCS is achievable. Interconnection of the control systems with existing building mechanical and electrical systems is also possible, but may require some modifications.

CEGS-15950 and TM 5-815-3 are good design guidance documents that meet their primary objective: to help improve the HVAC control systems designed and procured by the Government. CEGS-15950 and TM 5-815-3 can help designers to design better standard control systems and assemble contract packages. These design documents can also help manufacturers to better understand the design packages, to construct the panels, and to install and commission the standard control systems, according to the designs and specifications. This process can be supplemented with the quality verification user guide developed in this study, which includes checksheets to assist personnel in reviewing submittal and equipment.

The submittals, commissioning, and performance verification sections of the CEGS are valuable specifications that can spur the industry to provide better control systems and documentation. Users such as the Government can stimulate industry to follow this direction by emphasizing the desire for improved HVAC controls and documentation. This project has shown that some contractors have trouble meeting documentation requirements for several reasons, because: (1) many contractors find specifications difficult to understand, (2) contractors are often unfamiliar with writing specifications in the detail required by the CEGS; and (3) contractors often suffer shortages of both time and money.

On the basis of this demonstration, the following recommendations are made:

1. The submittals section of CEGS 15950 should be rewritten.

2. Detailed commissioning procedures and report forms, and detailed performance verification test procedures and report forms should be developed and included as part of the CEGS 15950.

3. A guidance for retrofitting standard HVAC control systems needs to be developed.

4. Laboratory researchers should be involved in field demonstrations of the processes they investigate. This demonstration, for example, revealed specific modifications required to retrofit digital controls to standard HVAC systems. The information derived from this work made possible the Hunstville division PROSPECT course on the subject of HVAC controls.

METRIC CONVERSION TABLE

1 in.	=	25.4 mm
1 ft	=	0.305 m
1 sq ft	=	0.093 m^2
1 cu ft	=	0.028 m^3
1 μm	=	1×10^{-6} m
°F	=	(°C × 1.8) + 32

REFERENCES

Dolan, William, *Validation Data for Mechanical System Algorithims Used in Building Energy Analysis Programs*, Technical Report (TR) E-177/ADA115182 (U.S. Army Construction Engineering Research Laboratories [USACERL], February 1982).

Chamberlin, Glen A., David M. Underwood, Dale L. Herron, and Victor L. Storm, *Retrofit of Standard Analog-Electronic Control Panels at Existing Army Facilities*, TR E-90/06/ADA226688 (USACERL, August 1990).

Conrad-Katz, Tracy, "FEAP Sees Promise in New HVAC Control Panels," *DEH Digest*, Vol 2, No. 3 (U.S. Army Engineering and Housing Support Center [USAEHSC], August 1989a), p 21.

Conrad-Katz, Tracy, ed., "HVAC Control Systems," *Technology Transfer Bulletin*, Vol 1, No. 89-3 (USAEHSC, August 1989b), p 3.

Corps of Engineers Guide Specification (CEGS) 15950, *Heating, Ventilating and Air Conditioning (HVAC) Control Systems* (U.S. Army Corps of Engineers [USACE], July 1990).

Hittle, Douglas C., and David L. Johnson, *New Control Design Principles Based on Measured Performance and Energy Analysis of HVAC Systems*, Interim Report (IR) E-85/02/ADA151708 (USACERL, January 1985).

Hittle, D.C., et al., "Theory Meets Practice in a Full-Scale Heating, Ventilating, and Air-Conditioning Laboratory," *ASHRAE Journal* (American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE], November 1982).

Partnership, Kling-Linquist, *State-of-the-Art Technologies for HVAC Control Systems*, Report prepared for Huntsville Division, U.S. Army Corps of Engineers (August 1986).

Pauli, David, and Dana Finney, "Heating and Cooling With Control," *Technology Transfer Bulletin*, Vol 3, No. 91-1 (USAEHSC, October 1990), p 1.

Schwenk, David M., Dale L. Herron, and Victor E. Alessi, *Standard Single-Loop Digital Controller for HVAC Systems*, TR E-90/14/ADA228326 (USACERL, September 1990).

"Technology Transfer," *Reporter* (American Public Works Association, Chicago, IL, October 1989), p 22.

Technical Manual (TM) 5-815-3, *Heating, Ventilating and Air Conditioning (HVAC) Control Systems* (USACE, September 1990).

APPENDIX A: HVAC Control System Sequence of Operation: Variable Air Volume System 02 and Hydronic Heating System 01

Start-Up Modes

Air handling unit 2 can be placed under control by setting the hand-off-auto (HOA) switch, located in the motor control center, in either the HAND or AUTO positions. (Figure A1 shows the schematic for Brown Hall VAV System #2.)

(Note: power must be present at the SLDC panel for the fans to start. Normally open safety shutdown relay contact R10-01 prevents starting of the fans if the SLDC panel does not have power. This feature is for temperature and fire protection.)

Hand Control

In the HAND position the supply fan motor starter (MS01) is energized. With MS01 energized, N.O. contact MS01-01 closes, energizing the return fan motor starter (MS03). Also, with MS01 energized, N.O. contact MS01-02 closes, illuminating the fan-on pilot light (PL09) and energizing the controls enable relay (R13). With R13 energized, N.O. contacts R13-01, R13-02, R13-03 and R13-04 close, which then permits the mixed air temperature, cooling coil discharge air temperature, supply duct static pressure, and return fan volume controllers to modulate their controlled devices. Figure A2 shows a ladder diagram of the Brown Hall control system.

(Note: For the MAT and CCDAT controller signals to pass to the controlled devices the system must not be in the ventilation delay mode, thus R12-01 and R12-02 will be closed.)

AUTO Control

In the AUTO position, the control panel mode of operation is under time clock (TC01-02) control.

Time clock modes of operation are: occupied, unoccupied, and delayed ventilation, and are summarized below:

Mode Name	Days Used	Time	On/Off	Time	Clock Load
Occupied	Everyday	0600	On	Load	1
Delayed Vent	Everyday	0600	On	Load	2
Delayed Vent	Everyday	0630	Off	Load	2
Occupied	Everyday	2300	Off	Load	1
Occupied	Sunday	0600	Off	Load	1
Delayed Vent	Sunday	0600	Off	Load	2

Monday through Saturday at 0600 time-clock-scheduled closure of time clock load contacts TC01-01 (occupied) and TC01-02 (delayed vent) energize the occupied relay (R01) and delayed vent relay (R02), and illuminate the occupied pilot light (PL01-02) and the delayed vent pilot light (PL02-02).

With R01 energized, the system is in the occupied mode, and N.O. contact R01-01 closes, thus energizing the supply fan start relay (R07). With R07 energized, N.O. contact R07-01 closes, thus

energizing the supply fan motor starter (MS01). With MS01 energized, N.O. contact MS01-01 closes, thus energizing the return fan motor starter MS03. Also with MS01 energized, N.O. contact MS01-02 closes, thus illuminating the fan on pilot light and energizing the controls enable relay (R13). With R13 energized, N.O. contacts R13-01, R13-02, R13-03 and R13-04 close, permitting the mixed air temperature, discharge air temperature, supply duct static pressure, and return fan volume controllers to modulate their controlled devices. Also, with R01 energized, N.O. contact R01-02 closes, thus energizing the cooling coil/mixed air enable relay (CC/MA enable) (R12). (Figure A3 shows the ladder diagrams for the Brown Hall control system motor starter.)

With R02 energized, the system is in the delayed ventilation mode, and N.C. relay contact R02-02 opens, breaking the circuit thereby placing the N.C. outdoor, N.C. relief and N.O. return air dampers in their normal positions. Also with R02 energized, N.C. contact R02-01 opens, prohibiting the exhaust fan from starting.

Monday through Saturday at 0630, time-clock-scheduled opening of delayed vent time clock contact (TC01-02) de-energizes the delayed ventilation relay (R02) and the delayed vent pilot light turns off. With R02 de-energized, the system is no longer in the delayed ventilation mode, N.C. contact R02-02 closes, completing the circuit, thereby permitting the outdoor, relief and return air dampers to be modulated.

Monday through Saturday at 2300, time-clock-scheduled opening of the time clock contact (TC01-01) de-energizes the occupied relay (R01) and extinguishes the occupied pilot light. With R01 de-energized, the panel is in the unoccupied mode, N.O. contact R01-01 opens, thus de-energizing the supply fan motor starter (MS01). With MS01 de-energized, N.O. contact MS01-01 opens, thus de-energizing the return fan motor starter (MS03). Also, with MS01 de-energized, N.O. contact MS01-02 opens, thus de-energizing the controls enable relay (R13) and extinguishing the fan-on pilot light. With R13 de-energized, its N.O. contacts open prohibiting the mixed air temperature, discharge air temperature, supply duct static pressure, and return fan volume controllers from modulating their controlled devices.

The exhaust fan is interlocked with the return fan motor starter (MS03) via N.O. auxilliary contact MS03-01. When MS03 energizes the exhaust fan can start. The air compressor is on at all times.

Mixed Air Temperature and Economizer Control

The mixed air temperature (MAT) controller (CNTL02-0202) modulates the outdoor, return, and relief air dampers to maintain a mixed air temperature of 54 °F; assuming that the air temperatures are low enough to achieve the setpoint. The MAT transmitter (TT02-0202), located in the mixed air section of the ductwork, sends a 4 to 20 mA signal, which represents the MAT value, to the MAT controller. The MAT controller then compares the actual MAT to the setpoint and sends out a 4 to 20 mA signal to modulate the dampers.

The economizer controller (CNTL10-0210) determines whether or not the MAT controller output signal passes to the high signal select module (HSS01-0202), based on a comparison between signals received from the outdoor air temperature (OAT) transmitter (TT10-0210) and the return air temperature (RAT) transmitter (TT11-0210). The economizer will "turn on" and energize the economizer relay (R09) when the outdoor air temperature (remote setpoint) input to the economizer controller is 5 °F less than the return air temperature (process variable) input to the economizer controller and the return air temperature is greater than 73 °F. With R09 energized, N.O. contact R09-01 closes permitting the MAT controller output to pass to the high signal select module (HSS01-0202). Also with R09 energized, N.O. contact R09-02 closes, illuminating the economizer on pilot light (PL03).

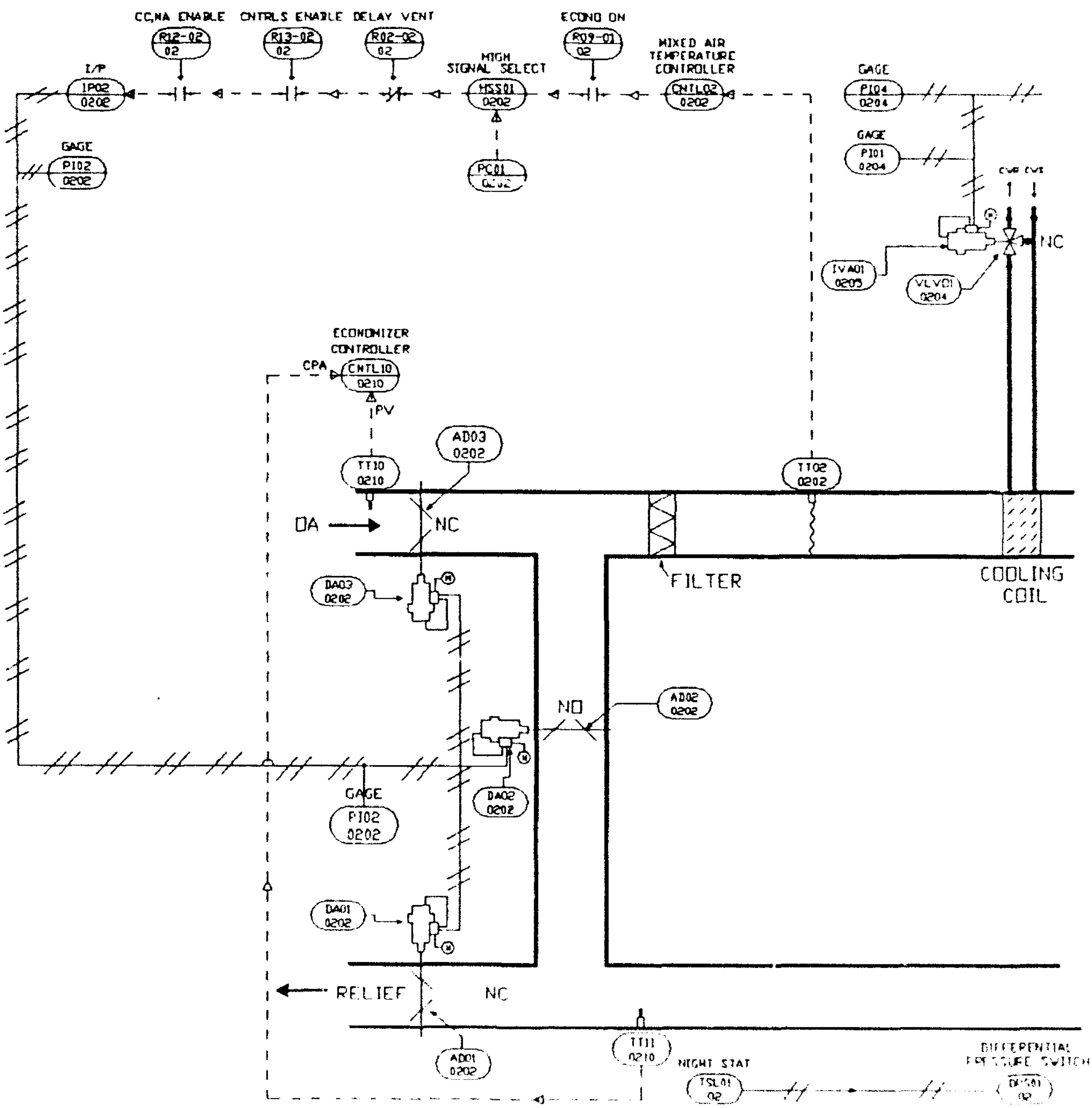


Figure A1. Schematic View of Control for Brown Hall - VAV System #2.

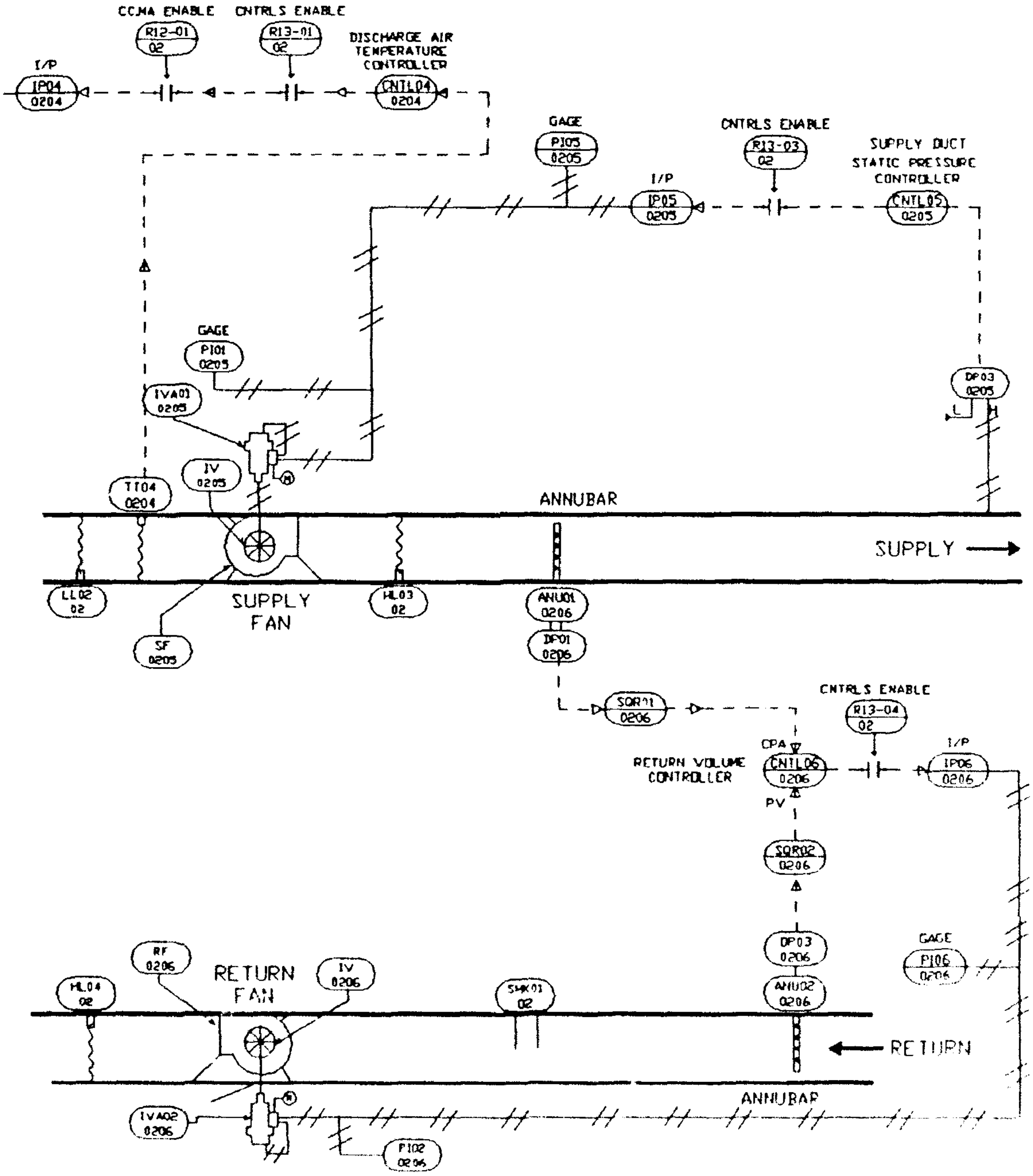


Figure A1. (Cont'd).

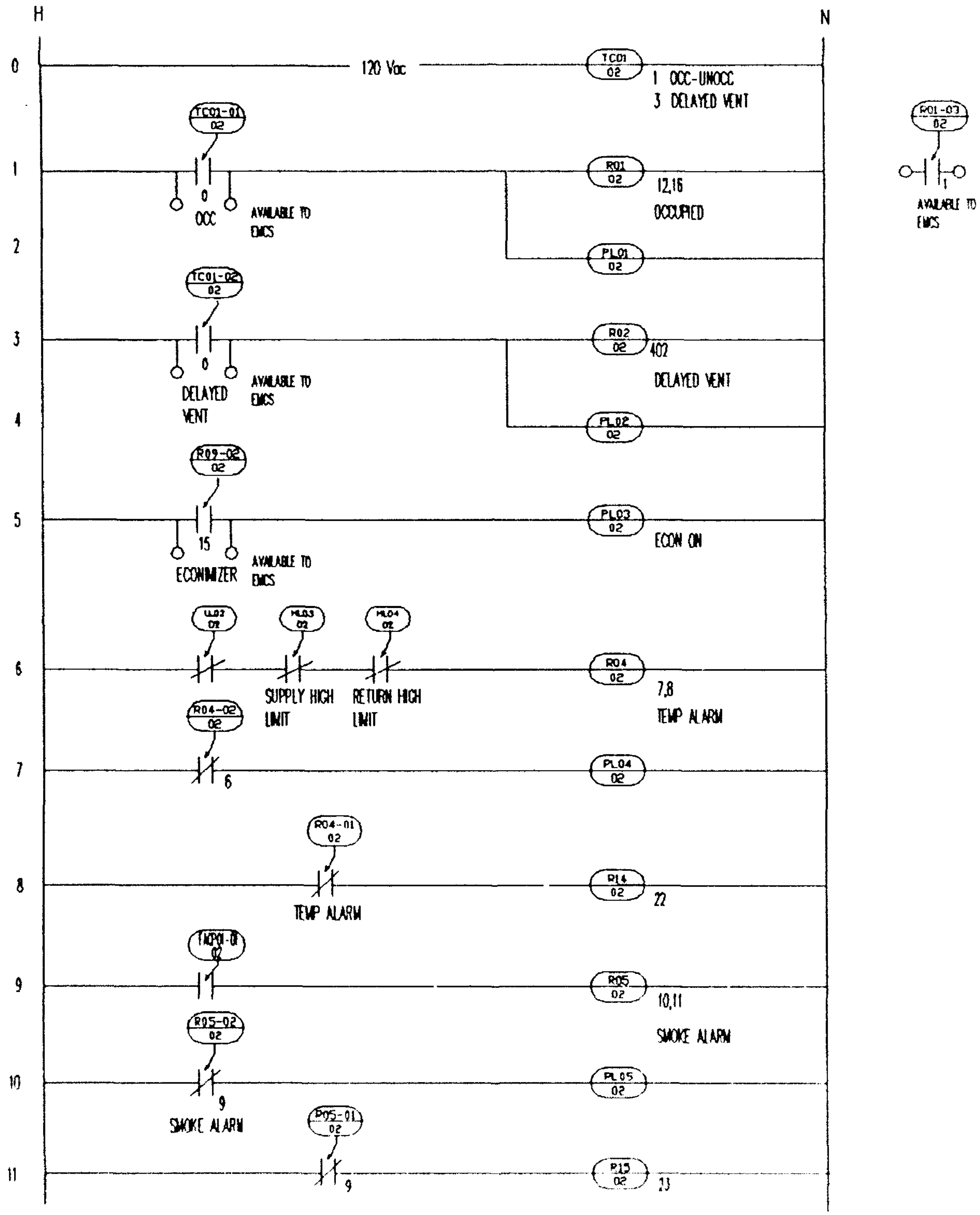


Figure A2. Ladder Diagram for Brown Hall Control System.

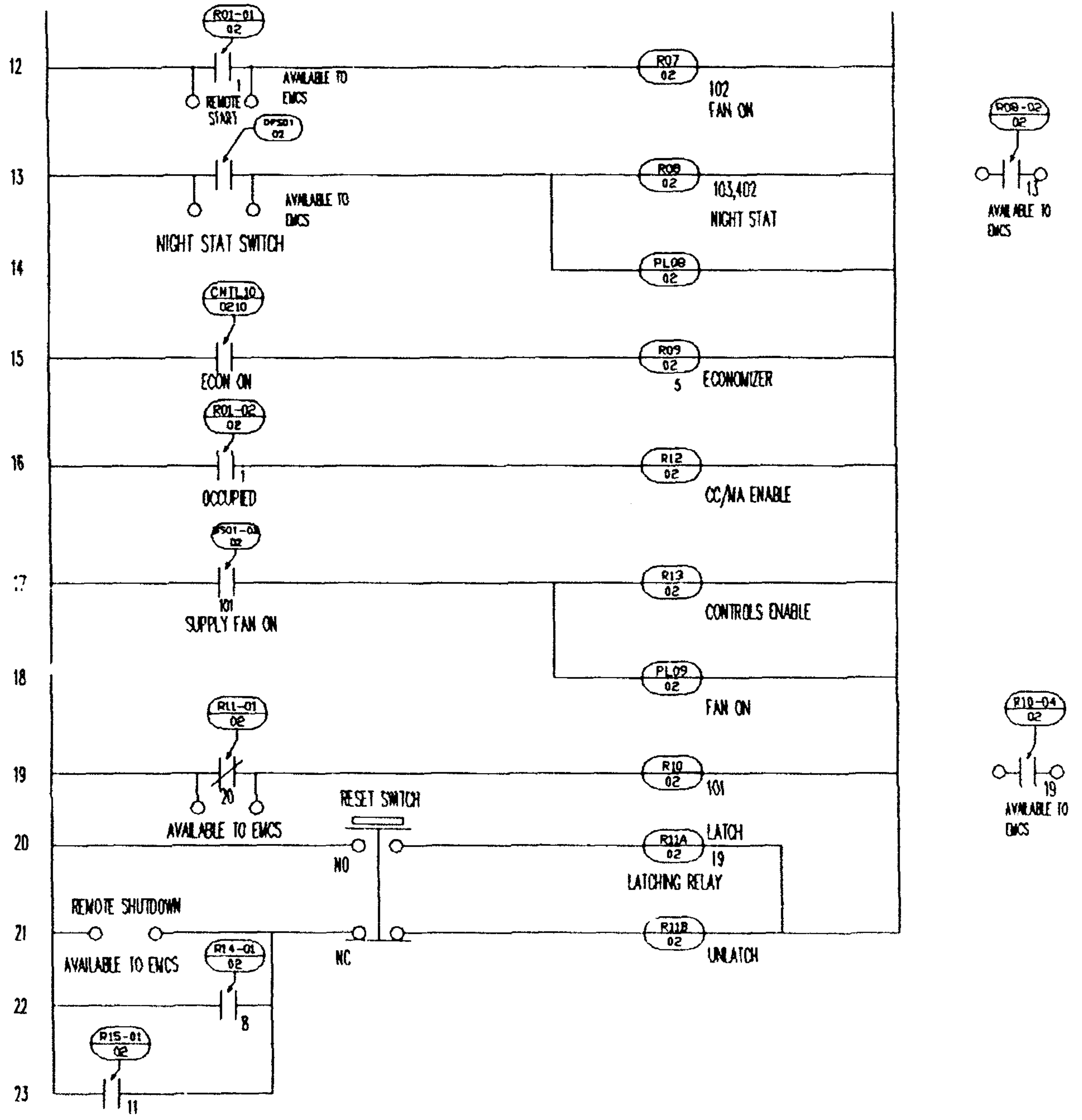


Figure A2. (Cont'd).

The high signal select module (HSS01-0202) accepts inputs from the MAT controller and the outside air damper minimum position signal from pot conditioner (PC01-0202). HSS01-0202 selects and passes the larger of these two signals to the mixed air dampers through the current to pneumatic (I/P) transducer (IP02-0202) when relay contacts R02-02, R13-02, and R12-02 are closed.

Cooling Coil Discharge Air Temperature Control

The cooling coil discharge air temperature (DAT) controller (CNTL04-0204) modulates the N.C. cooling coil valve (VLV01-0204) to maintain the discharge air temperature of 54 °F. The DAT transmitter (TT04-0204), located in the supply air section of the ductwork, sends a 4 to 20 mA signal, which represents the DAT value, to the DAT controller. The DAT controller then compares the actual DAT to the setpoint and sends out a 4 to 20 mA signal to modulate the valve. The 4 to 20 mA output signal from the DAT controller is transduced into a 3 to 15 ps. pneumatic signal by I/P transducer (IP04-0204), which then modulates the cooling-coil valve actuator (VA01-0204), when relay contacts R12-01 and R13-01 are closed.

Supply Duct Pressure Control

The supply duct static pressure (SDSP) controller (CNTL05-0205) modulates the supply-fan-inlet-guide vanes to maintain a duct static pressure of 2.5 inches of water column; assuming that the supply fan is on. The supply duct static pressure sensor/transmitter assembly (DP03-0205), located downstream of the supply fan, sends a 4 to 20 mA signal, which represents the static pressure value, to the SDSP controller. The SDSP controller then compares the actual static pressure to the setpoint and sends out a 4 to 20 mA signal to modulate the inlet guide vanes so that the static pressure setpoint is maintained. The 4 to 20 mA output signal from the SDSP controller is transduced into a 3 to 15 psi pneumatic signal by I/P transducer (IP05-0205), which then modulates the supply-fan-inlet-guide-vane actuator (IVA01-0205), when the controls enable relay contact (R13-03) is closed.

Return Fan Volume Control

The return fan volume controller (CNTL06-0206) modulates the return-fan-inlet-guide vanes to maintain a volumetric air flow that is 1000 cfm less than the supply air flow. The return-air annubar sensor/transmitter assembly (DP02-0206), located upstream of the return fan, sends a 4 to 20 mA signal to the square root extractor (SQR02-0206), which then sends a 4 to 20 mA signal, which represents the return air flow, to the return fan volume controller. The return fan volume controller converts the signal into a volumetric air flow (cfm) and then compares the actual return air volumetric flow to the setpoint and sends out a 4 to 20 mA signal to modulate the return-fan inlet guide vanes so that the setpoint is maintained. The setpoint is determined by the supply air volumetric flow. The supply duct annubar sensor/transmitter assembly (DP01-0206), located downstream of the supply fan, sends a 4 to 20 mA signal to the square root extractor (SQR01-0206), which then sends sends a 4 to 20 mA signal, which represents the supply air flow, to the return fan volume controller (CNTL06-0206). The RFV controller converts the signal into a volumetric air flow (cfm), then ratios the cfm value to account for the difference in supply and return duct cross sectional areas, and subtracts (bias) 1000 cfm, thus establishing the return fan volume controller's setpoint at 1000 cfm less than the actual supply duct volumetric air flow. The 4 to 20 mA output signal from the RFV controller is transduced into a 3 to 15 psi pneumatic signal by I/P transducer (IP06-0206), which then modulates the return-fan-inlet-guide-vane actuator (IVA02-0206), when the controls enable relay contact (R13-04) is closed.

Hot Water Temperature Control With OA RESET

The hot water temperature controller (CNTL03-0203) modulates the heat exchanger's N.C. high temperature hot water (HTHW) valve (VLV02-0203) to maintain the hot water supply temperature setpoint. The HWST sensor/transmitter assembly (TT12-0203), located in the medium temperature water supply line, sends a 4 to 20 mA signal to the HWT controller. The HWT controller then compares the actual hot water supply temperature to the setpoint and sends out a 4 to 20 mA signal to modulate the valve. The 4 to 20 mA signal from the HWT controller is transduced into a 3 to 15 psi pneumatic signal by I/P transducer (IP03-0203), which then modulates the HTHW valve actuator (VA02-0203). The hot water temperature controller setpoint is established by the hot water reset controller (CNTL11-0203) based on the outdoor air temperature signal from temperature transmitter assembly (TT13-0203). The hot water temperature controller setpoint is reset according to the hot water reset schedule shown on the drawings.

The hot water reset controller contains a process variable alarm, which energizes the hot water pump motor starter (MS05) when the outdoor air temperature drops below 60 °F. With MS05 energized, N.O. contact MS05-01 closes, which then energizes electric to pneumatic switch (EPS01-0203). With EPS01-0203 energized, its normally closed port opens, permitting the signal from the pneumatic transducer (IP03-0203) to modulate the HTHW valve (VLV02-0203).

Special Interlocks

Power to the panel can be turned off using the switch located at the right side of the SLDC panel, or by disconnecting power at the breaker panel located in room 29.

A night stat (TSL01-02), located in the second floor hallway, activates the differential pressure switch (DPS01), located in the AC power panel below the SLDC panel, if the hallway temperature drops below 55 °F. With DPS01 activated, night stat relay (R08) energizes and the nite stat pilot light (PL08) illuminates. With R08 energized, N.O. contact R08-01 closes, energizing the supply fan motor starter (MS01). With MS01 energized, N.O. contact MS01-01 closes, energizing the return fan motor starter (MS03). N.O. contact MS01-02 also closes, illuminating the fan-on pilot light (PL07) and energizing the controls enable relay R13). With R13 energized, N.O. contact R13-01, R13-02, R13-03, and R13-04 close, which permits the mixed air temperature, discharge air temperature, supply duct static pressure, and return fan volume controllers to modulate their controlled devices. During unoccupied periods time clock occupied contact (TC01-01) would be open thus de-energizing the occupied relay (R01). With R01 de-energized, N.O. contact R01-02 is open, thus de-energizing the cooling coil/mixed air enable relay (CC/MA enable) R12. With R12 de-energized the N.C. cooling coil valve and N.C OA and relief air dampers remain closed.

The fire alarm control panel (FACP) INTERLOCK relay (FACP01) de-energizes when a fire/smoke alarm is received by the fire alarm control panel. With FACP01 de-energized, N.C contact FACP01-01 opens, de-energizing the smoke alarm relay (R05). With R05 de-energized, N.C. contact R05-02 closes illuminating the smoke alarm pilot light (PL05). Also, with R05 deenegized, N.C. contact R05-01 closes, which energizes R15. With R15 energized, N.O. contact R15-01 closes, which unlatches the latching relay (R11). With R11 unlatched, contact R11-01 opens, de-energizing the safety shutdown relay (R10). With R10 de-energized, N.O. contact R10-01 opens, de-energizing the supply fan motor starter (MS01), shutting down the supply fan. With MS01 de-energized, N.O. contact MS01-01 opens, thus de-energizing the return fan motor starter (MS03). Also, with MS01 de-energized, N.O. contact MS01-02 opens, thus de-energizing the controls enable relay (R13) and extinguishing the fan-on pilot light. With R13 de-energized, its N.O. contacts open prohibiting the mixed air temperature, discharge air temperature, supply duct static pressure, and return air volume controllers from modulating their controlled devices. The

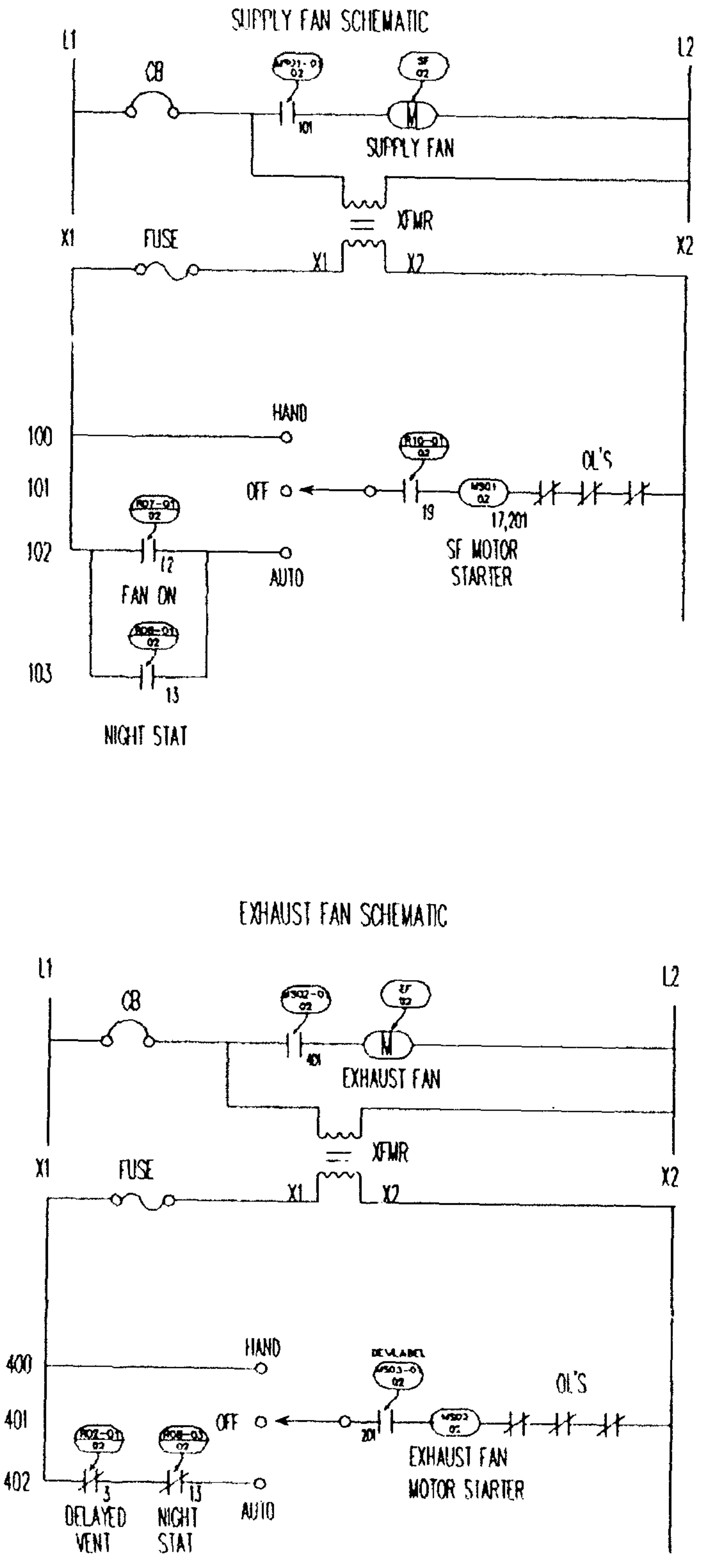
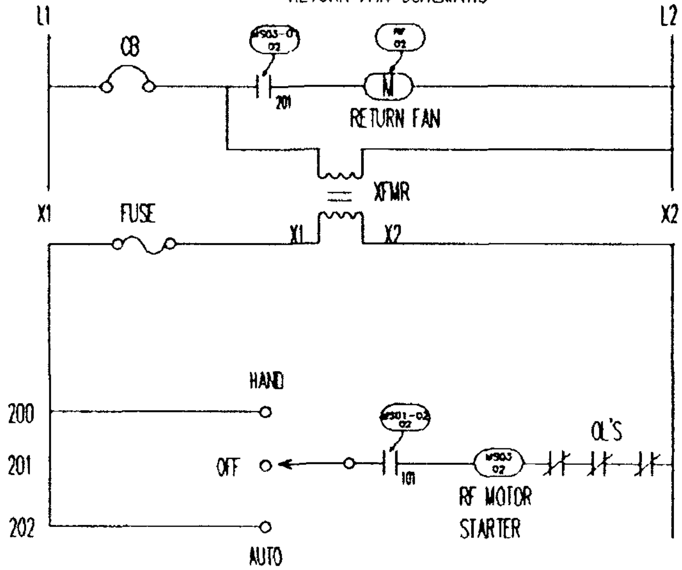


Figure A3. Motor Starter Diagrams for Brown Hall Control System.

RETURN FAN SCHEMATIC



HW SUPPLY SCHEMATIC

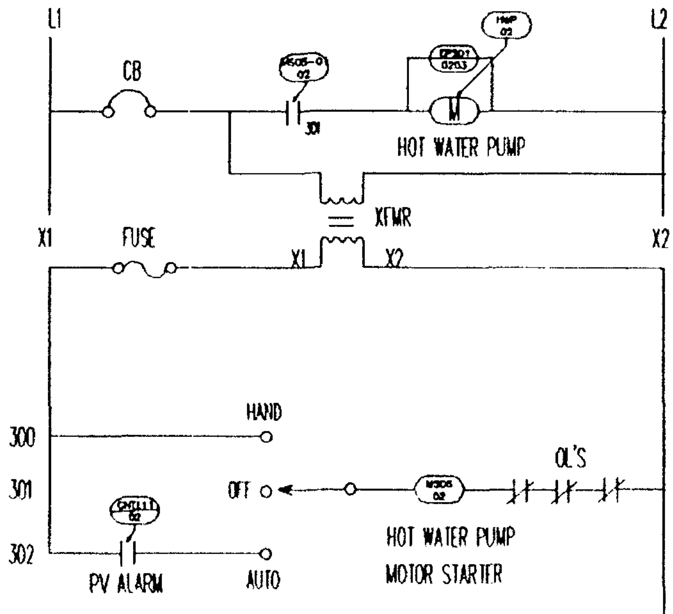


Figure A3. (Cont'd).

exhaust fan is interlocked with the return fan motor starter (MS02) via N.O. auxilliary contact MS02-01. When MS02 de-energizes the exhaust fan is turned off.

The N.C. freeze stat (LL02) and N.C. high temperature limit trip (HL03) in the supply duct, and the N.C. high temperature limit trip (HL04) in the return duct sense extreme conditions in the ductwork. These devices are interlocked with the SLDC panel safety shutdown relay R10 through the latching relay (R11). If either contacts LL02, HL03, or HL04 open, temp alarm relay R04 de-energizes. With R04 de-energized, N.C contact R04-02 closes, which illuminates the temperature alarm pilot light (PL04). Also, with R04 de-energized, N.C contacts R04-01 close, which energizes R14. With R14 energized, N.O. contact R14-01 closes, which unlatches the latching relay (R11). With R11 unlatched, contact R11-01 opens, de-energizing the safety shutdown relay (R10). With R10 de-energized, N.O. contact R10-01 opens, de-energizing the supply fan motor starter (MS01), shutting down the supply fan. With MS01 de-energized, N.O. contact MS01-01 opens, thus de-energizing the return fan motor starter (MS03). Also, with MS01 de-energized, N.O. contact MS01-02 opens, thus de-energizing the controls enable relay (R13) and extinguishing the fan on pilot light. With R13 de-energized, its N.O. contacts open prohibiting the mixed air temperature, discharge air temperature, supply duct static pressure, and return air volume controllers from modulating their controlled devices. The exhaust fan is interlocked with the return fan motor starter (MS02) via N.O. auxilliary contact MS02-01. When MS02 de-energizes the exhaust fan is turned off.

The AHU will remained shutdown after a temperature or smoke alarm until the device that tripped the alarm and the reset switch in the SLDC panel are reset. (Figures A4 and A5 show the inner door and back plate layouts for the Brown Hall control panel.)

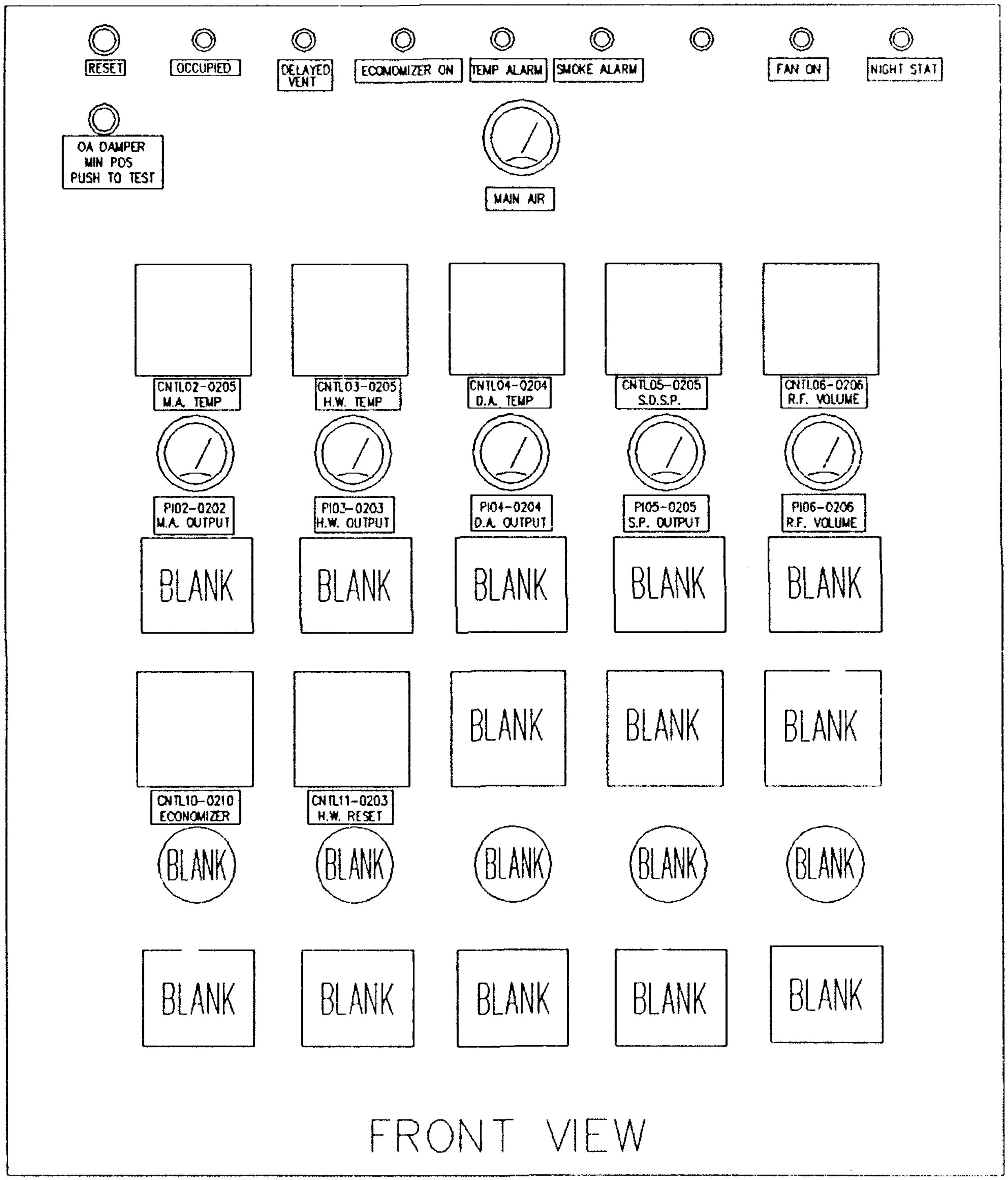


Figure A4. As-Built Inner Door Layout for Brown Hall Control Panel.

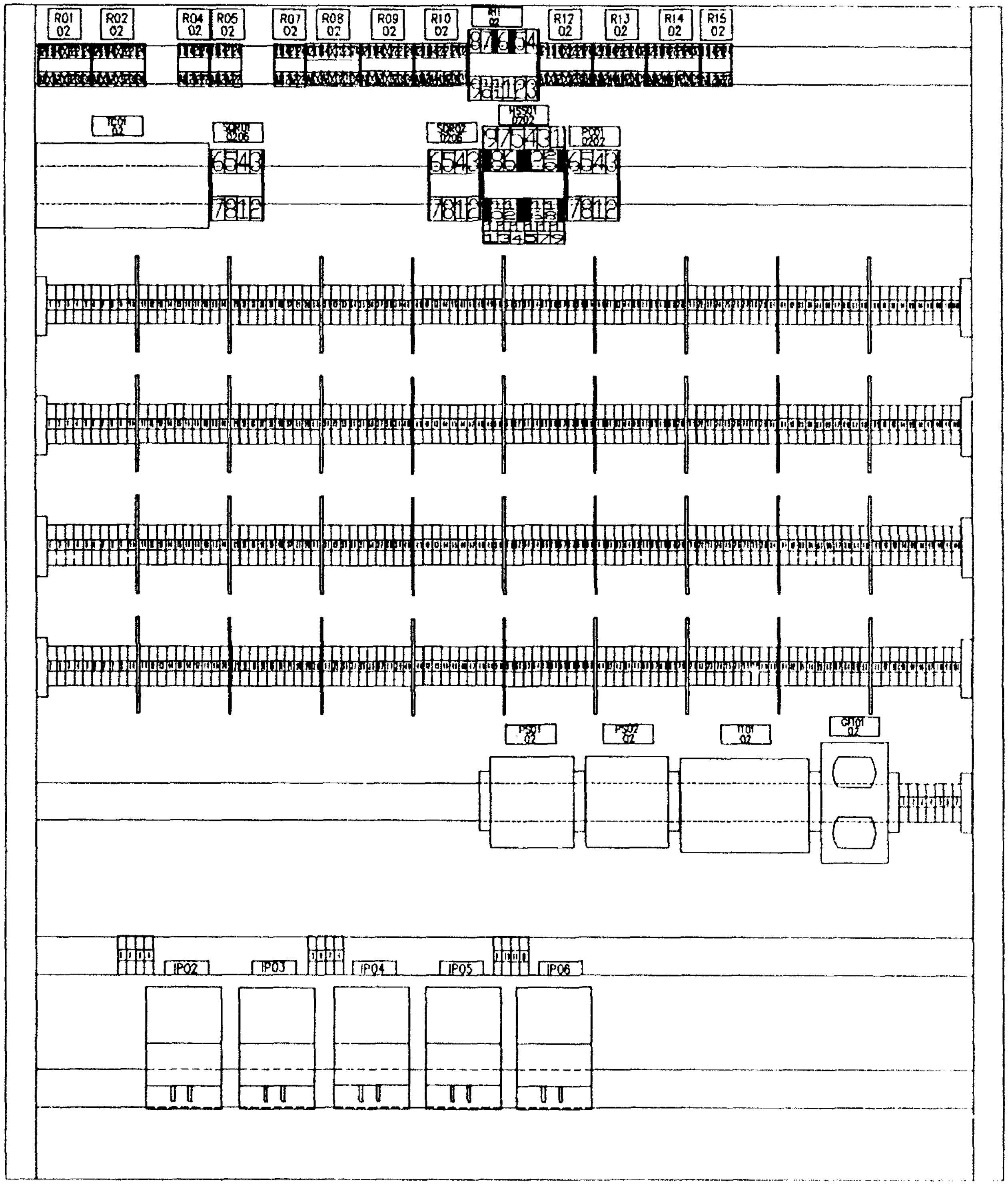


Figure A5. As-Built Back Plate Layout for Brown Hall Control Panel.

APPENDIX B: Commissioning Procedures Variable Air Volume System With Return Fan System #2 and Outside-Air Temperature-Scheduled Hydronic-Heating System #1 at Brown Hall, Fort Leonard Wood, MO

General Procedures

The personnel performing the commissioning of the systems should refer to the Operation and Maintenance Instructions and Equipment Data Booklet for specific information dealing with calibration, configuring, tuning, and adjusting of specific devices and components.

The commissioning personnel shall tune controllers, conduct observations, make adjustments, perform calibrations, take measurements, and do tests of the control systems, and make any necessary control system corrections to ensure that the systems functions as described in the sequence of operation.

Signals used to change the mode of operation shall originate from the actual HVAC control device intended for the purpose. External input signals to the HVAC control panel, such as EMCS and starter auxiliary contacts, may be simulated in steps 1, 2, and 3. With each operational-mode-change signal, observe that the proper pilot lights and HVAC panel output contacts function.

Weather-dependent procedures that cannot be performed by simulation shall be performed in the appropriate season. When simulation is used, the contractor shall verify the actual results in the appropriate season.

A two-point calibration accuracy check of all HVAC control system sensor/transmitter assemblies, and sensor/transducer assemblies shall be performed by comparing the HVAC control-panel readout to the actual value of the process variable measured at the sensor or measurement-array location. Digital indicating test instruments shall be used, such as digital thermometers. The test instruments shall be at least twice as accurate as the specified sensor-to-controller readout accuracy. Calibration accuracy checks shall verify that the sensor-to-controller-readout accuracies at the two points are within the specified product tolerances. If the accuracy is outside tolerance ranges, controller and transmitter ranges should be checked, faulty devices replaced and the calibration accuracy check should be repeated. The HVAC system shall be checked while in two conditions, the first while in the shutdown condition and the second while in an operational condition.

For insertion-temperature and immersion-temperature sensor-to-controller-readout accuracy checks, measurement of temperatures shall be checked at one physical location along the axis of the sensor, in the proximity of the sensor.

For averaging-temperature sensor-to-controller-readout accuracy checks, measurement of the temperature shall be checked every 2 ft along the axis of the sensor, in the proximity of the sensor. A maximum of 10 readings shall be averaged.

To establish stable conditions prior to making measurement for calibration accuracy checks, commissioning personnel shall place the controllers in the manual mode, and adjust the controller output, as the means of manipulating control devices, such as dampers and valves.

Commissioning personnel shall perform controller configuration and tuning procedures. The procedure shall consist of setting the initial proportional, integral, and derivative (PID) constants, ranges for remote setpoint, process variables, controller setpoints, and logging the settings. Tuning shall be self-tuning operation by the controller unless manual tuning is necessary.

I COMMISSIONING PROCEDURES—VARIABLE AIR VOLUME SYSTEM WITH RETURN FAN SYSTEM #2

1 Shutdown Condition Checks

Shutdown condition checks are done to ensure that a sufficient level of control is available when the HVAC system is first started.

1.1 System Inspection

Observe the HVAC system in shutdown condition. Place the hand-off-auto (HOA) switches for supply fan (SF-0205), return fan (RF-0206) and hot water pump (PUMP01-0203) in the "off" position, thus disabling the control signals and ensuring that all devices will be in their "normal" position. Apply power to the panel by flipping panel power switch (S1) to the "on" position. Check to see that power and main air are available at the HVAC system control panel (the main air gage should read between 20 and 25 psi). Referring to the VAV control system schematic drawing, check to see that all temperature, air flow and static pressure sensors, temperature alarm sensors, and smoke alarm sensors have been properly located. Check to see that the outside-air dampers (AD03-0202), relief-air dampers (AD01-0202), return-fan inlet guide vanes (IV-0206), supply-fan inlet guide vanes (IV-0205) and cooling-coil valve (VA01-0204) are closed, and the return-air dampers (AD02-0202) are open.

1.2 Controller Configuration

1. General: The controllers, which must be configured are: economizer (CNTL10-0210), mixed air temperature (MAT) (CNTL02-0202), discharge air temperature (DAT) (CNTL04-0204), supply duct static pressure (SDSP) (CNTL05-0205) and return fan volume (RFV) (CNTL06-0206).

2. Delivered state: All controllers are delivered/installed without the dip switches and configuration parameters being set, or the internal jumpers in place.

3. Responsibilities: It is the commissioning personnel's responsibility to set the controllers' dip switches, configuration parameters and internal jumpers and replace any faulty controllers.

4. Adjustment procedures: Refer to the user manuals for each controller, located in the Operation Instruction Booklet, for scrolling through the controller settings and locations of dip switches and jumpers.

5. Settings: Dip switches settings, configuration parameters and internal jumper settings for each controller are listed on each controller configuration checksheet, located in the Operation Instruction Booklet.

1.3 Time Clock Configuration

1. General: The time clock (TC01-02) is the only component to be setup in this step.

2. Delivered state: The time clock is delivered/installed without the dip switches and configuration parameters being set, or the internal jumpers in place.

3. Responsibilities: It is the commissioning personnel's responsibility to set dip switches, configuration parameters, and internal jumpers, and replace the time clock if it is faulty.

4. Adjustment procedures: Refer to the time clock user manual, located in the Operation Instruction Booklet, for scrolling through the time clock setting and locations of dip switches and jumpers.

5. Settings: Dip switches settings, configuration parameters and internal jumper settings are listed on the time clock configuration checksheet, located in the Operation Instruction Booklet.

1.4 Adjustments and Calibration Checks of Controlled Device Circuits

1.4.1 Mixed Air Damper Circuit

1. General: The components, which must be checked or adjusted are: the MAT controller (CNTL02-0202)(output); the MAT I/P (IP02-0202); the outside air damper (AD03-0202), actuator (DA03-0202) and pilot positioner; the return air damper (AD02-0202), actuator (DA02-0202) and pilot positioner; and the relief air damper (AD01-0202), actuator (DA01-0202) and pilot positioner.

2. Delivered state: The MAT controller is factory-calibrated to output a 4 to 20 mA signal for a zero to 100 percent controller output range, and should require no adjustments. The current-to-pneumatic transducer (I/P) is factory set to give a 3 to 15 psi output for a corresponding 4 to 20 mA input and should require no adjustments. The damper actuators are factory-calibrated for 8 to 13 psi ranges and should require no adjustments. The dampers should have been installed so that they assume their "normal" position when the low signal is applied to the actuator. The pilot positioners are not set up for the appropriate ranges so adjustments are required.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuits perform correctly, set up the pilot positioners so that they operate over the correct ranges, make any necessary adjustments, and replace any faulty components. Should problems occur, the commissioning personnel should refer to the Maintenance Instruction Booklet for diagnostic, adjustment, and repair procedures.

4. Calibration check, settings and adjustment procedures for the return air damper: Place a jumper from pin 20 of terminal strip 1 to pin 3 terminal strip 5, and a jumper from pin 19 of terminal strip 1 to pin 4 of terminal strip 5, thus bypassing any open contacts in the circuit. Confirm the operation of the MAT I/P (IP02-0202) by placing the mixed air temperature controller (CNTL02-0202) in manual mode and adjusting the controller output to zero and 100 percent. The MAT pressure gage (PI02-0202) should read 3 and 15 psi, respectively. Adjust the MAT controller output so that MAT pressure gage reads 3.5 psi, then adjust the zero screw on the pilot positioner of the return air damper actuator (DA02-0202) so that the return air dampers (AD02-0202) are fully open. Adjust the MAT controller output so that the MAT pressure gage reads 14.5 psi, then adjust the span spring on the pilot positioner of the return air damper actuator so that the return air dampers are fully closed. Repeat the low and high signals and check for correct action of the dampers. Leave the jumpers connected and the MAT controller in the manual mode.

5. Calibration check, settings and adjustment procedures for the relief air damper: Adjust the MAT controller (CNTL02-0202) output so that MAT pressure gage (PI02-0202) reads 3.5 psi, then adjust the zero screw on the pilot positioner of the relief air damper actuator (DA01-0202) so that the relief air dampers (AD01-0202) are fully closed. Adjust the MAT controller output so that MAT pressure gage reads 14.5 psi, then adjust the span spring on the pilot positioner of the relief air damper actuator so that the relief air dampers are fully open. Repeat the low and high signals and check for correct action of the dampers. Leave the jumpers connected and the MAT controller in manual mode.

6. Calibration check, settings and adjustment procedures for the outside air damper: Adjust the MAT controller (CNTL02-0202) output so that MAT pressure gage (PI02-0202) reads 3.5 psi, then adjust the zero screw on the pilot positioner of the outside air damper actuator (DA03-0202) so that the outside air dampers (AD03-0202) are fully closed. Adjust the MAT controller output so that the MAT pressure gage reads 14.5 psi, then adjust the span spring on the pilot positioner of the outside air damper actuator so that the outside air dampers are fully open. Remove the jumpers and place the MAT controller in the auto mode.

1.4.2 Supply Fan Inlet Guide Vane Circuit

1. General: The components, which must be checked or adjusted are: the supply duct static pressure (SDSP) controller (CNTL05-0205); the SDSP I/P (IP05-0205); and the supply fan inlet guide vanes (IV-0205), actuator (IVA01-0205) and pilot positioner.

2. Delivered state: The SDSP controller is factory-calibrated to give a 4 to 20 mA signal for a zero to 100 percent controller output range, and should require no adjustments. The current-to-pneumatic transducer (I/P) is factory set to give a 3 to 15 psi output for a corresponding 4 to 20 mA input and should require no adjustments. The inlet guide vane actuator is factory-calibrated for 8 to 13 psi ranges and should require no adjustments. The guide vanes should have been installed so that they assume their "normal" position (closed) when the low signal is applied to the actuator. The pilot positioners are not set up for the appropriate ranges so adjustments are required.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, set up the pilot positioner so that it operates over the correct range, make any necessary adjustments, and replace any faulty components. Should problems occur, the commissioning personnel should refer to the Maintenance Instruction Booklet for diagnostic, adjustment and repair procedures.

4. Calibration check, settings and adjustment procedures: Place a jumper from pin 50 terminal strip 1 to pin 9 terminal strip 5, thus bypassing any open contacts in the circuit. Place the supply duct static pressure (SDSP) controller (CNTL05-0205) in manual mode. Check the operation of the SDSP I/P (IP05-0205) by placing the (SDSP) controller in manual mode and adjusting the controller output to zero and 100 percent. The SDSP pressure gage (PI05-0205) should read 3 and 15 psi, respectively. Adjust the SDSP controller output so that SDSP pressure gage reads 3.5 psi, then adjust the zero screw on the pilot positioner of the supply fan inlet guide vane damper actuator (IVA01-0205) so that the supply fan inlet guide vane dampers (IV-0205) are fully closed. Adjust the controller output so that SDSP pressure gage reads 14.5 psi. Adjust the span spring on the pilot positioner of the supply fan inlet guide vane damper actuator so that the supply fan inlet guide vane dampers are fully open. Remove the jumper.

1.4.3 Return Fan Circuit

1. General: The components that must be checked or adjusted are: the return fan volume (RFV) controller (CNTL06-0206); the RFV I/P (IP06-0206); and the return fan inlet guide vanes (IV-0206), actuator (IVA02-0206), and pilot positioner.

2. Delivered state: The RFV controller is factory-calibrated to give a 4 to 20 mA signal for a zero to 100 percent controller output range, and should require no adjustments. The current-to-pneumatic transducer (I/P) is factory set to give a 3 to 15 psi output for a corresponding 4 to 20 mA input and should require no adjustments. The guide vane actuator is factory-calibrated for 8 to 13 psi ranges and should require no adjustments. The inlet guide vanes should be installed so that they assume their "normal"

position (closed) when the low signal is applied to the actuator. The pilot positioners are not set up for the appropriate ranges so adjustments are required.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, set up the pilot positioner so that it operates over the correct range, make any necessary adjustments, and replace any faulty components. Should problems occur, the commissioning personnel should refer to the Maintenance Instruction Booklet for diagnostic, adjustment and repair procedures.

4. Calibration check, settings and adjustment procedures: Place a jumper from pin 14 of the RFV controller to pin 11 terminal strip 5, thus bypassing any open contacts in the circuit. Place the return fan volume (RFV) controller (CNTL06-0206) in manual mode. Check the operation of the RFV I/P (IP06-0206) by placing the return fan volume controller in manual mode and adjusting the controller output to zero and 100 percent. The RFV pressure gage (PI06-0206) should read 3 and 15 psi, respectively. Adjust the RFV controller output so that RFV pressure gage reads 3.5 psi. Adjust the zero screw on the pilot positioner of the return fan inlet guide vane damper actuator (IVA02-0206) so that the return fan inlet guide vane dampers (IV-0206) are fully closed. Adjust the RFV controller output so that the RFV pressure gage reads 14.5 psi. Adjust the span spring on the pilot positioner of the return fan inlet guide vane damper actuator so that the return fan inlet guide vane dampers are fully open. Remove the jumper.

1.4.4 Cooling Coil Valve Circuit

1. General: The components that must be checked or adjusted are: the discharge air temperature (DAT) controller (CNTL04-0204); the DAT I/P (IP04-0204); and the cooling coil valve (VLV01-0204), actuator (VA01-0204) and pilot positioner.

2. Delivered state: The DAT controller is factory-calibrated to give a 4 to 20 mA signal for a zero to 100 percent controller output range, and should require no adjustments. The current-to-pneumatic transducer (I/P) is factory set to give a 3 to 15 psi output for a corresponding 4 to 20 mA input and should require no adjustments. The valve actuator is factory-calibrated for an 8 to 13 psi range and should require no adjustments. The cooling coil valve should be installed so that it assumes its "normal" position (closed) when the low signal is applied to the actuator. The pilot positioner is not set up for the appropriate range so adjustments are required.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, set up the pilot positioner so that it operates over the correct range, make any necessary adjustments, and replace any faulty components. Should problems occur, the commissioning personnel should refer to the Maintenance Instruction Booklet for diagnostic, adjustment and repair procedures.

4. Calibration check, settings and adjustment procedures: Place a jumper from pin 40 terminal strip 1 to pin 7 terminal strip 5, thus bypassing any open contacts in the circuit caused. Place the discharge air temperature (DAT) controller (CNTL04-0204) in manual mode. Check the operation of the DAT I/P (IP04-0204) by placing the DAT controller in manual mode and adjusting the controller output to zero and 100 percent. The DAT pressure gage (PI04-0204) should read 3 and 15 psi, respectively. Adjust the DAT controller output so that DAT pressure gage reads 3.5 psi, then adjust the zero screw on the pilot positioner of the cooling coil valve actuator (VA01-0204) so that the cooling coil valve (VLV01-0204) is fully closed. Adjust the controller output so that DAT pressure gage reads 14.5 psi. Adjust the span spring on the pilot positioner of the cooling coil valve actuator so that the cooling coil valve is fully open. Remove the jumper.

2 Operating Condition Checks

2.1 Occupied/Delayed Ventilation Mode Startup Check

Prior to start-up, set the SDSP and RFV controllers (CNTL05-0205, CNTL06-0206) in the MANUAL mode and adjust the outputs to 50 percent. Reset the time clock set times so that the HVAC system is in the unoccupied mode. Place the HOA switches for the supply, return, and exhaust fans in the auto position. Reset the time clock set times so that the system will be in the ventilation delay and occupied mode. Observe that the vent delay, occupied and fan on pilot lights illuminate, the supply and return fans start, and the exhaust fan will not start. Check that the outside air damper (AD03-0202) and relief damper (AD01-0202) are completely closed and the return air damper (AD02-0202) is open. Check that the cooling coil valve (VLV01-0204) and the supply and return inlet guide vanes (IV-0205, IV-0206) can be modulated by placing the controllers in the manual mode and varying the controller outputs. If the economizer is not "on," place a jumper from pin 20 of terminal strip 1 to pin 4 on the high signal select module (HSS01-0202), place the MAT controller in manual, vary the MAT controller output, and observe that the air dampers do not move. Leave the jumper connected.

2.2 Occupied/Ventilation Mode Operation Check

Change the time clock set times so the system is in the occupied, ventilation mode, and observe that the vent delay pilot light turns off. Change the MAT controller output and observe that the outside air, return air and relief air dampers modulate. leave the jumper connected. Check to see that the exhaust fan will now turn on.

2.3 Unoccupied Shutdown Check

Change the time clock's shutdown time so that the system will be in the unoccupied mode. Observe that the occupied and fan on pilot lights turn off and the fans shut down. Change the MAT controller output and observe that the outside air, return air and relief air dampers do not move. Remove the jumper connected. Change the DAT controller output and observe that the cooling coil valve does not move. Change the SDSP controller output and observe that the supply fan inlet guide vanes do not modulate. Change the RFV controller output and observe that the return fan inlet guide vanes do not modulate. Note that the exhaust fan will not start.

2.4 Calibration Check of Sensing Circuits

Change the time clock set times so that the system is in the occupied, ventilation mode.

2.4.1 Return Air Temperature (RAT) Circuit

1. General: The components that must be checked or adjusted are: the economizer controller (CNTL10-0210) (RAT reading); and the RAT transmitter (TT11-0210) and RTD.

2. Delivered state: Configuration of the economizer controller in previous steps should have set up the controller to perform properly, thus no adjustments should be required. The temperature transmitter is factory set for the appropriate range, thus no adjustments should be required. Resistive temperature detectors (RTDs) are manufactured to give a standard response to different temperatures and require no adjustments.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, make any necessary adjustments, and replace any faulty components.

4. Adjustment procedures: If adjustments or repair are needed for the sensing circuit, follow the procedures located in the Maintenance Instruction Booklet.

5. Settings: Controller and transmitter ranges and RTD responses can be found in the Operation and Maintenance Instruction Booklets and in the equipment schedule sections of the shop drawings.

6. Calibration check: The return air temperature is displayed as the process variable (upper display) on the economizer controller (CNTL10-0210). Measure the RAT at two different values using a digital thermometer and compare the values to the controller's RAT display.

2.4.2 Outside Air Temperature (OAT) Circuit

1. General: The components that must be checked or adjusted are: the economizer controller (OAT reading); and the OAT transmitter (TT10-0210) and RTD.

2. Delivered state: Configuration of the economizer controller in previous steps should have set up the controller to perform properly, thus no adjustments should be required. The temperature transmitter is factory set to the appropriate setting, thus no adjustments should be required. Resistive temperature detectors (RTD) are manufactured to give a standard response to different temperatures and require no adjustments.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, make any necessary adjustments, and replace any faulty components.

4. Adjustment procedures: If adjustments or repair are needed for the sensing circuit, follow the procedures located in the Maintenance Instruction Booklet.

5. Settings: Controller and transmitter ranges and RTD responses can be found in the Operation and Maintenance Instruction Booklets and in the equipment schedule sections of the shop drawings.

6. Calibration check: The outside air temperature is displayed as the remote setpoint (lower display) on the economizer controller (CNTL10-0210). Measure the OAT at two different values using a digital thermometer and compare the values to the controller's OAT display.

2.4.3 Mixed Air Temperature (MAT) Circuit

1. General: The components that must be checked or adjusted are: the MAT controller (MAT reading); and the MAT transmitter (TT02-0202) and RTD.

2. Delivered state: Configuration of the MAT controller in previous steps should have set up the controller to perform properly, thus no adjustments should be required. The temperature transmitter is factory set to the appropriate setting, thus no adjustments should be required. Resistive temperature detectors (RTDs) are constructed to give a standard response to different temperatures and require no adjustments.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, make any necessary adjustments, and replace any faulty components.

4. Adjustment procedures: If adjustments or repair are needed for a sensing circuit, follow the procedures located in the Maintenance Instruction Booklet.

5. Settings: Controller and transmitter ranges and RTD responses can be found in the Operation and Maintenance Instruction Booklet and in the equipment schedule sections of the shop drawings.

6. Calibration check: The mixed air temperature is displayed as the process variable (upper display) on the mixed air temperature controller (CNTL02-0202). Measure the MAT at two different values using a digital thermometer and compare the values to the controller's MAT display.

2.4.4 Discharge Air Temperature (DAT) Circuit

1. General: The components that must be checked or adjusted are: the DAT controller (DAT reading); and the DAT transmitter (TT04-0204) and RTD.

2. Delivered state: Configuration of the DAT controller in previous steps should have set up the controller to perform properly, thus no adjustments should be required. The temperature transmitter is factory set to the appropriate setting, thus no adjustments should be required. Resistive temperature detectors (RTD) are constructed to give a standard response to different temperatures and require no adjustments.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, make any necessary adjustments, and replace any faulty components.

4. Adjustment procedures: If adjustments or repair are needed for a sensing circuit, follow the procedures located in the Maintenance Instruction Booklet.

5. Settings: Controller and transmitter ranges and RTD responses can be found in the Operation and Maintenance Instruction Booklet and in the equipment schedule sections of the shop drawings.

6. Calibration check: The discharge air temperature is displayed as the process variable (upper display) on the discharge air temperature controller (CNTL04-0204). Measure the DAT at two different values using a digital thermometer and compare the values to the controller's DAT display.

2.4.5 Supply Duct Static Pressure (SDSP) Circuit

1. General: The components that must be checked or adjusted are: the SDSP controller (SDSP reading); and the SDSP differential pressure transmitter/transducer (DP03-0205) and sensor.

2. Delivered state: Configuration of the SDSP controller in previous steps should have set up the controller to perform properly thus no adjustments should be required. The differential pressure transmitter/transducer is factory to give a specific current output for a specific differential pressure input thus no adjustments should be required. The differential pressure sensor is factory thus no adjustments should be required.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, make any necessary adjustments, and replace any faulty components.

4. Adjustment procedures: If adjustments or repair are needed for a sensing circuit, follow the procedures located in the Maintenance Instruction Booklet.

5. Settings: Controller and transmitter/transducer settings and ranges can be found in the Operation and Maintenance Instruction Booklet and in the equipment schedule sections of the shop drawings.

6. Calibration check: The supply duct static pressure is displayed as the process variable (upper display) on the supply duct static pressure controller (CNTL05-0205). Measure the SDSP at two different values using a pitot tube and compare the values to the controller's SDSP display.

2.4.6 Supply Duct Volumetric Air Flow (SDVAF) Circuit

1. General: The components that must be checked or adjusted are: the RFV controller (SDVAF reading); the supply air flow square root extractor (SQR01-0206); and the supply air differential pressure (SADP) transmitter/transducer (DP01-0206) and sensor (ANU01-0206).

2. Delivered state: Configuration of the RFV controller in previous steps should have set up the controller to perform properly thus no adjustments should be required. The SADP transmitter/transducer is factory thus no adjustments should be required. The supply air flow sensor (annubar) is constructed to give a standard response to different air flows thus no adjustments should be required.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, make any necessary adjustments, and replace any faulty components.

4. Adjustment procedures: If adjustments or repair are needed for a sensing circuit, follow the procedures located in the Maintenance Instruction Booklet.

5. Settings: Controller and transmitter settings and ranges can be found in the Operation and Maintenance Instruction Booklet and in the equipment schedule sections of the shop drawings.

6. Calibration check: The supply duct volumetric air flow (SDVAF) is displayed as the remote setpoint (lower display) on the return fan volume controller (CNTL06-0206). (Note: The SDVAF displayed by the controller will be different from the actual SDVAF. To compare the actual to the displayed value, multiply the displayed value by 10, then add 1000 cfm.) Measure the SDVAF at two different values using a pitot tube and compare the values to the controller's SDVAF display.

2.4.7 Return Duct Volumetric Air Flow (RDVAF) Circuit

1. General: The components that must be checked or adjusted are: the RFV controller (RDVAF reading); the return air flow square root extractor (SQR02-0206); and the RADP transmitter/transducer (DP02-0206) and sensor (ANU02-0206).

2. Delivered state: Configuration of the RFV controller in previous steps should have set up the controller to perform properly thus no adjustments should be required. The RADP transmitter/transducer is factory-calibrated, thus no adjustments should be required. The return duct air flow sensor (annubar) is constructed to give a standard response to different air flows thus no adjustments should be required.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, make any necessary adjustments, and replace any faulty components.

4. Adjustment procedures: If adjustments or repair are needed for a sensing circuit, follow the procedures located in the Maintenance Instruction Booklet.

5. Settings: Controller and transmitter settings and ranges can be found in the Operation and Maintenance Instruction Booklet and in the equipment schedule sections of the shop drawings.

6. Calibration check: The return duct volumetric air flow is displayed as the process variable (upper display) on the return fan volume controller (CNTL06-0206). (Note: The RDVAF displayed by the controller will be different from the actual RDVAF. To compare the actual to the displayed value, multiply the displayed value by 10.) Measure the RDVAF at two different values using a pitot tube and compare the values to the controller's values.

2.5 Controller Tuning Procedures

2.5.1 Static Pressure Control Tuning

Place a jumper from pin 20 of terminal strip 1 to pin 4 on the high signal select module, place the MAT controller in manual and decrease the output to zero percent so that the return air dampers are fully open. Set the supply duct static pressure controller (CNTL05-0205) in the AUTO mode, perform the controller tuning procedure, and log the P, I, and D settings. Leave the jumper connected.

2.5.2 Return Fan Volume Control Tuning

Place the return fan volume controller (CNTL06-0206) in the AUTO mode, perform the controller tuning procedure, and log the P, I, and D settings.

2.5.3 Repeat Steps 2.5.1 and 2.5.2

Repeat steps 2.5.1 and 2.5.2 until the P, I, and D values for each controller remain the same or change an insignificant amount, and stable control is achieved.

2.5.4 Minimum Outside Air and Economizer Control Check

Set the supply duct static pressure controller (CNTL05-0205) and mixed air temperature controller (CNTL02-0202) in the manual mode and adjust the fan speed until the specified minimum supply air flow is achieved. Adjust the minimum-outside-air potentiometer (PC01-0202) until the correct amount of outside air is being introduced. (See the Operation and Maintenance Instruction Booklet or the equipment schedule for the amount of outside air).

Apply the economizer on signal and observe that the economizer pilot light illuminates and the air dampers can be modulated by changing the mixed air controller output.

2.5.5 Mixed Air Temperature Control Tuning

Place the mixed air temperature controller (CNTL02-0202) in the AUTO mode, perform the controller tuning procedure, and log the P, I, and D settings.

2.5.6 Cooling-Coil Discharge Air Temperature Control

Place the discharge air temperature controller (CNTL04-0204) in the AUTO mode, perform the controller tuning procedure, and log the P, I, and D settings.

2.6 VAV Terminal Box Checks

Set velocity setpoints for minimum and maximum flow, and temperature setpoints for the heating/cooling dead band for each VAV terminal unit. Observe and verify the actions of the controller, and the operation of the damper. Verify that space temperature is maintained.

2.7 Alarm Condition Checks:

2.7.1 Night Stat Check

1. General: The components to be checked are: the night stat (TSL01-02) and the differential pressure switch (DPS01-02) and night stat relay (R08-02)

2. Delivered state: DPS01-02 is factory set and requires no adjustments. The night stat (TSL01-02) can be adjusted to activate when the space temperature drops below a specified setting.

3. Responsibilities: It is the commissioning personnel's responsibility to confirm that the circuit performs correctly and set the setpoint of the night stat to the value shown on the drawings.

4. Adjustment procedures: See the equipment data.

5. Settings: See the Operation and Maintenance Instruction Booklet.

6. Calibration and operational check: Adjust the night thermostat setpoint upward so that the night stat activates. Observe that the night stat and fan on pilot lights turn on and the occupied pilot light remains off. Observe that the supply and return fans start and the exhaust fan remains off. Place the DAT controller in manual, change the output and observe that the cooling coil valve remains closed. If the economizer is not "on," place a jumper from pin 20 of terminal strip 1 to pin 4 on the high signal select module (HSS01-0202) then place the MAT controller in manual, vary the output and observe that the air dampers do not move. Turn the night stat setpoint downward and observe that the HVAC system shuts down. Set the night thermostat setpoint to the specified setting.

2.7.2 Smoke Detector:

1. General: The components to be checked are: the smoke detector (SMK01-02), the fire alarm contact (FACP01-01-02) and the smoke alarm relay (R05-02).

2. Delivered state: The smoke detector is factory set to the appropriate setting and thus no adjustments should be required.

3. Responsibilities: It is the commissioning personnel's responsibility to confirm that the circuit performs correctly.

4. Adjustment procedures: See equipment data.

5. Settings: See equipment data.

6. Operational check: With the HVAC system running, simulate a smoke alarm by opening the fire alarm contact (FACP01-01-02) located above the fire alarm control panel. Simulation shall be performed without false-alarming any life safety systems. Observe that the HVAC system shuts down and the smoke alarm pilot light turns on. Verify contact output at the EMCS terminals. Reset the fire alarm contacts and note that the system does not restart and the smoke alarm pilot light remains illuminated. Press the panel reset button and observe that the smoke alarm pilot light turns off and the HVAC system starts.

2.7.3 High Return Air Temperature LIMIT

1. General: The components to be checked are: the return air high temperature thermostat (HL04-02) and the temperature alarm relay (R04-02).

2. Delivered state: The high temperature thermostat (HL04-02) will require setting of the temperature setpoint.

3. Responsibilities: It is the commissioning personnel's responsibility to confirm that the circuit performs correctly and set the setpoint of the thermostat.

4. Adjustment procedures: See equipment data.

5. Settings: See the Operation and Maintenance Instruction Booklet.

6. Calibration and operational check: With the HVAC system running, simulate a high return duct temperature alarm by decreasing the trip setpoint on the high limit switch so that an alarm is present. Observe HVAC system shutdown, observe and verify contact output at the EMCS terminal, and observe that the temperature alarm pilot light turns on. Reset the thermostat to the specified setting, press the reset button on the thermostat and observe that the temperature alarm light remains illuminated and the HVAC system remains shut down. Press the panel reset button and observe that the temperature alarm pilot light turns off and the HVAC system starts.

2.7.4 Low Supply Air Temperature Limit (Freeze Stat)

1. General: The components to be checked are: the supply air low temperature thermostat (LL02-02) and the temperature alarm relay (R04-02).

2. Delivered state: The low temperature thermostat (freeze stat) (LL02-02) will require setting of the temperature setpoint.

3. Responsibilities: It is the commissioning personnel's responsibility to confirm that the circuit performs correctly and set the setpoint of the thermostat.

4. Adjustment procedures: See equipment data.

5. Settings: See the Operation and Maintenance Instruction Booklet.

6. Calibration and operational check: With the HVAC system running, simulate a low temperature alarm by increasing the trip setpoint so that an alarm is present. Observe HVAC system shutdown, observe and verify contact output at the EMCS terminal, and observe that the temperature alarm pilot light turns on. Set the low limit thermostat to the specified setting and press the reset switch on the thermostat, observe that the temperature alarm light remains illuminated and the HVAC system remains shut down Press the panel reset button and observe that the temperature alarm pilot light turns off and the HVAC system starts.

2.7.5 High Discharge Air Temperature Limit

1. General: The components to be checked are: the supply air high temperature thermostat (HL03-02) and the temperature alarm relay (R04-02).

2. Delivered state: The high temperature thermostat (HL03-02) will require setting of the temperature setpoint.

3. Responsibilities: It is the commissioning personnel's responsibility to confirm that the circuit performs correctly and set the setpoint of the thermostat.

4. Adjustment procedures: See equipment data.

5. Settings: See the Operation and Maintenance Instruction Booklet.

6. Operational check: With the HVAC system running, simulate a high supply air temperature alarm by depressing the supply duct high temperature alarm thermostat test button or by decreasing the trip setpoint so that an alarm is present. Observe HVAC system shutdown, observe and verify contact output at EMCS terminal, and observe that the temperature alarm pilot light turns on. Set the thermostat at the specified setting. Restart the HVAC system by manual reset and observe that the temperature alarm pilot light turns off.

II COMMISSIONING PROCEDURES OUTSIDE-AIR TEMPERATURE-SCHEDULED HYDRONIC-HEATING SYSTEM #1

1 Shutdown Condition Checks

The shutdown condition checks are done to ensure that a sufficient level of control is available when the HVAC system is first started.

1.1 System Inspection

Observe the HVAC system in its shutdown condition. Place the hand-off-auto (HOA) switch for the hot water pump (PUMP01-0203) in the "off" position, thus disabling the control signal to the high temperature hot water (HTHW) valve and ensuring that it will be in its normally closed position. Apply power to the panel by flipping panel power switch (S1) to the "on" position. Check to see that power and main air are available at the HVAC system control panel. (The main air gage should read between 20 and 25 psi). Referring to the HW control system schematic drawing, check to see that all temperature sensors have been properly located. Check to see that the HTHW valve (VLV02-0203) is closed.

1.2 Controller Configuration

1. General: The controllers that must be configured are: hot water reset (CNTL11-0203), hot water temperature (CNTL03-0203).

2. Delivered state: All controllers are delivered/installed without the dip switches and configuration parameters being set, or the internal jumpers in place.

3. Responsibilities: It is the commissioning personnel's responsibility to set the controllers' dip switches, configuration parameters and internal jumpers and replace any faulty controllers.

4. Adjustment procedures: Refer to the user manuals for each controller, located in the Operation Instruction Booklet, for scrolling through the controller settings and locations of dip switches and jumpers.

5. Settings: Dip switches settings, configuration parameters and internal jumper settings for each controller are listed on each controller configuration checksheet, located in the Operation Instruction Booklet.

2 Operating Condition Checks

2.1 Startup Control Check

The heating system on-off operation is not controlled by the control panel's time clock. The HOA switch located in the motor control center and the HWR controller (CNTL11-0203) control the on-off operation of the heating system.

Prior to start up, set the HWT controller (CNTL03-0203) in the manual mode and adjust the output to zero percent. Start the HW pump by placing the HW pump HOA switch in the AUTO position.

2.2 Adjustments and Calibration Checks of HTHW Valve Circuit

1. General: The components that must be checked or adjusted are: the HWT controller (output); the HWT I/P; the electric-to-pneumatic switch (EPS01-0203), and the HTHW valve, actuator and pilot positioner.

2. Delivered state: The HWT controller is factory-calibrated to output a 4 to 20 mA signal for a zero to 100 percent controller output range, and should require no adjustments. The current-to-pneumatic transducer (I/P) is factory set to give a 3 to 15 psi output for a corresponding 4 to 20 mA input and should require no adjustments. The E/P switch is factory set and should require no changes. The valve actuator is factory-calibrated for an 8 to 13 psi range and should require no adjustments. The valve should have been installed so that it assume its "normal" closed position when the low signal is applied to the actuator. The pilot positioners are not set up for the appropriate ranges so adjustments are required.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuits perform correctly, set up the pilot positioners so that they operate over the correct ranges, make any necessary adjustments, and replace any faulty components. Should problems occur, the commissioning personnel should refer to the Maintenance Instruction Booklet for diagnostic, adjustment and repair procedures.

4. Calibration check, settings and adjustment procedures: Confirm the operation of the HWT I/P (IP03-0203) by placing the HWT controller (CNTL03-0203) in manual mode and adjusting the controller output to zero and 100 percent. The HWT pressure gage (PI03-0203) should read 3 and 15 psi, respectively. Adjust the HWT controller output so that HWT pressure gage reads 3.5 psi, then adjust the zero screw on the pilot positioner of the HTHW Valve actuator (VA02-0203) so that the hthw valve is completely closed. Adjust the HWT controller output so that HWT pressure gage reads 14.5 psi, then adjust the span spring on the pilot positioner of the HTHW valve actuator so that the HTHW valve is fully open. Repeat the low and high signals and check for correct action of the valve.

2.3 Outside Air Temperature (OAT) Circuit

1. General: The components that must be checked or adjusted are: the HWR controller (OAT reading); and the OAT transmitter (TT13-0203) and RTD.

2. Delivered state: Configuration of the HWR controller in previous steps should have set up the controller to perform properly, thus no adjustments should be required. The temperature transmitters are factory set to the appropriate setting thus no adjustments should be required. Resistive temperature detectors (RTD) are manufactured to give a standard response to different temperatures and require no adjustments.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, make any necessary adjustments, and replace any faulty components.

4. Adjustment procedures: If adjustments or repair are needed for the sensing circuit, follow the procedures located in the Maintenance Instruction Booklet.

5. Settings: Controller and transmitter ranges and RTD responses can be found in the Operation and Maintenance Instruction Booklets and in the equipment schedule sections of the shop drawings.

6. Calibration check: The outside air temperature is displayed as the process variable (upper display) on the HWR controller (CNTL13-0203). Measure the OAT at two different values using a digital thermometer and compare the values to the controller's OAT display.

2.4 Hot Water Temperature (HWT) Circuit

1. General: The components that must be checked or adjusted are: the HWT controller (HWT reading); and the HWT transmitter (TT12-0203) and RTD.

2. Delivered state: Configuration of the HWT controller in previous steps should have set up the controller to perform properly, thus no adjustments should be required. The temperature transmitters are factory set to the appropriate setting thus no adjustments should be required. Resistive temperature detectors (RTDs) are constructed to give a standard response to different temperatures and require no adjustments.

3. Responsibilities. It is the commissioning personnel's responsibility to confirm that the circuit performs correctly, make any necessary adjustments, and replace any faulty components.

4. Adjustment procedures: If adjustments or repair are needed for a sensing circuit, follow the procedures located in the Maintenance Instruction Booklet.

5. Settings: Controller and transmitter ranges and RTD responses can be found in the Operation and Maintenance Instruction Booklet and in the equipment schedule sections of the shop drawings.

6. Calibration check: The hot water temperature is displayed as the process variable (upper display) on the HWT controller (CNTL12-0203). Note the HWT displayed by the inline thermometer at two different values and compare the values to the controller's HWT display.

2.5 Hot Water Reset Control Check

Place the HW reset controller in the AUTO mode. Remove the OAT transmitter wires from the controller and connect a current source to the controller to simulate an outside air temperature. Adjust the current source so that an OAT value of 50 °F is displayed by the HWR controller. Refer to the hot water reset schedule on the HTHW control system schematic, the corresponding HWT setpoint (lower display) displayed on the HWT controller should be 140 °F. Simulate OATs of 25, 0.0 and -10 °F and confirm HWT setpoints of 170, 200 and 200 °F, respectively.

2.6 Hot Water Temperature Control Tuning

Place the HWT controller (CNTL03-0203) in the AUTO mode, perform the controller tuning procedure, and log the P, I, and D settings.

2.7 Outside Air Initiated System Shutdown

Simulate an OAT above 60 °F, observe that the HW pump turns off, and the HTHW valve cannot be modulated by placing the HWT controller in manual and changing the output.

2.8 Motor Control Center Shutdown

Place the HOA switch for the HW pump in the "off" position, note that the HW pump turns off, and the HTHW valve cannot be modulated by placing the HWT controller in manual and changing the output.

III COMMISSIONING REPORT: VARIABLE AIR VOLUME SYSTEM WITH RETURN FAN SYSTEM #2, BROWN HALL, FORT LEONARD WOOD, MO

1 SHUTDOWN CONDITION CHECKS

1.1 SYSTEM INSPECTION

1. Panel Power ______________________________
2. Motor HOA Switches ______________________________
3. Panel Power ______________________________
4. Main Air to Panel (20 psi) ______________________________
5. Location of devices correct
   - TT02-0202 ______________________________
   - TT11-0210 ______________________________
   - TT10-0210 ______________________________
   - TT04-0204 ______________________________
   - DP03-0205 ______________________________
   - ANU01-0206 ______________________________
   - ANU02-0206 ______________________________
   - HL03-02 ______________________________
   - LL02-02 ______________________________
   - HL04-03 ______________________________
   - SMK01-02 ______________________________
6. COMMENTS: ______________________________
7. OAD (AD03-0203) position ______________________________

8. READ (AD01-0201) position ______________________
9. RAD (AD02-0202) position ______________________
10. CCV (VLV01-0204) position ______________________
11. SFIGV (IV-0205) position ______________________
12. RFIGV (IV-0206) position ______________________
13. COMMENTS:

1.2 CONTROLLER CONFIGURATION
1. Economizer (CNTL10-0210) configured ______________________
2. MAT (CNTL02-0202) configured ______________________
3. DAT (CNTL04-0204) configured ______________________
4. SDSP (CNTL05-0205) configured ______________________
5. RFV (CNTL06-0206) configured ______________________
6. COMMENTS:

1.3 TIME CLOCK CONFIGURATION
1. Time Clock (TC01-02) configured ______________________
2. COMMENTS:

1.4 ADJUSTMENTS AND CALIBRATION CHECKS OF CONTROLLED DEVICE CIRCUITS
1.4.1 MIXED AIR DAMPER CIRCUIT
1. RETURN AIR DAMPERS (AD02-0202)
   1. CNTL02-0202 output 0.0 percent,
      IP02-0202 output psi ______________________
   2. CNTL02-0202 output 100 percent,
      IP02-0202 output psi ______________________
   3. IP02-0202 output 3.5 psi,
      AD02-0202 position ______________________
   4. IP02-0202 14.5 output psi,
      AD02-0202 position ______________________
   5. COMMENTS:

2. RELIEF AIR DAMPERS (AD01-0202)
   1. IP02-0202 output 3.5 psi,
      AD01-0202 position ______________________
   2. IP02-0202 14.5 output psi,
      AD01-0202 position ______________________
   3. COMMENTS:

3. OUTSIDE AIR DAMPERS (AD03-0202)
   1. IP02-0202 output 3.5 psi,
      AD03-0202 position ______________________
   2. IP02-0202 14.5 output psi,
      AD03-0202 position ______________________
   3. COMMENTS

1.4.2 SUPPLY FAN INLET GUIDE VANE CIRCUIT
1. CNTL05-0205 output 0.0 percent,
   IP05-0205 output psi ______________________
2. CNTL05-0205 output 100 percent,
   IP05-0205 output psi ______________________

3. IP05-0205 output 3.5 psi,
   IVA-0205 position ______________________
4. IP05-0205 14.5 output psi,
   IVA-0205 position ______________________
5. COMMENTS:

1.4.3 RETURN FAN INLET GUIDE VANE CIRCUIT

1. CNTL06-0206 output 0.0 percent,
   IP06-0206 output psi ______________________
2. CNTL06-0206 output 100 percent,
   IP06-0206 output psi ______________________
3. IP06-0206 output 3.5 psi,
   IVA-0206 position ______________________
4. IP06-0206 14.5 output psi,
   IVA-0206 position ______________________
5. COMMENTS:

1.4.4 COOLING COIL VALVE CIRCUIT

1. CNTL04-0204 output 0.0 percent,
   IP04-0204 output psi ______________________
2. CNTL04-0204 output 100 percent,
   IP04-0204 output psi ______________________
3. IP04-0204 output 3.5 psi,
   VA01-0204 position ______________________
4. IP04-0204 14.5 output psi,
   VA01-0204 position ______________________
5. COMMENTS:

2 OPERATING CONDITION CHECKS

2.1 OCCUPIED/DELAYED VENTILATION MODE STARTUP CHECK

1. CNTL05-0205 manual, 50 percent output ______________
2. CNTL06-0206 manual, 50 percent output ______________
3. Time Clock status ______________________
4. Supply, Return & Exhaust Fan HOA motor
   switches in AUTO position ______________________
5. Time Clock status ______________________
6. Occupied Light status ______________________
7. Fan ON Light status ______________________
8. Delayed Vent Light status ______________________
9. Supply Fan status ______________________
10. Return Fan status ______________________
11. Exhaust Fan status ______________________
12. OAD (AD03-0202) position ______________________
13. RAD (AD02-0202) position ______________________
14. READ (AD01-0202) position ______________________
15. VLV01-0204 modulation ______________________
16. SF-0205 modulation ______________________
17. RF-0206 modulation ______________________
18. Economizer ON or jumper in place ______________________

19. Air Damper modulation ______________________
20. COMMENTS:

2.2 OCCUPIED/VENTILATION MODE OPERATION CHECK

1. Time Clock status ______________________
2. Delayed Vent Light status ______________________
3. Air Damper modulation ______________________
4. Exhaust Fan status ______________________
5. COMMENTS:

2.3 UNOCCUPIED SHUTDOWN CHECK

1. Time Clock status ______________________
2. Occupied Light status ______________________
3. Fan ON light status ______________________
4. Supply Fan status ______________________
5. Return Fan status ______________________
6. Exhaust Fan status ______________________
7. Air Damper modulation ______________________
8. VLV01-0204 modulation ______________________
9. SF-0205 modulation ______________________
10. RF-0206 modulation ______________________
11. COMMENTS:

2.4 CALIBRATION CHECK OF SENSING CIRCUITS

2.4.1 RETURN AIR TEMPERATURE CIRCUIT

1. RAT controller display ______________________
2. RAT measured ______________________
3. RAT controller display ______________________
4. RAT measured ______________________
5. COMMENTS

2.4.2 OUTSIDE AIR TEMPERATURE CIRCUIT

1. OAT controller display ______________________
2. OAT measured ______________________
3. OAT controller display ______________________
4. OAT measured ______________________
5. COMMENTS

2.4.3 DISCHARGE AIR TEMPERATURE CIRCUIT

1. DAT controller display ______________________
2. DAT measured ______________________
3. DAT controller display ______________________
4. DAT measured ______________________
5. COMMENTS

2.4.4 SUPPLY DUCT STATIC PRESSURE CIRCUIT

1. SDSP controller display ______________________
2. SDSP measured ______________________
3. SDSP controller display ______________________

4. SDSP measured ______
5. COMMENTS

2.4.5 SUPPLY DUCT VOLUMETRIC AIR FLOW CIRCUIT
1. RFV SDVAF controller display ______
2. SDVAF measured ______
3. RFV SDVAF controller display ______
4. SDVAF measured ______
5. COMMENTS

2.4.6 RETURN DUCT VOLUMETRIC AIR FLOW CIRCUIT
1. RFV RDVAF controller display ______
2. RDVAF measured ______
3. RFV RDVAF controller display ______
4. RDVAF measured ______
5. COMMENTS

2.5 CONTROLLER TUNING PROCEDURES

2.5.1 STATIC PRESSURE CONTROL
1. SDSP controller in AUTO mode ______
2. Initial Proportional value ______
3. Initial Integral value ______
4. Initial Derivative value ______
5. Final Proportional value ______
6. Final Integral value ______
7. Final Derivative value ______
8. COMMENTS:

2.5.2 RETURN FAN VOLUME CONTROL
1. RFV controller in AUTO mode ______
2. Initial Proportional value ______
3. Initial Integral value ______
4. Initial Derivative value ______
5. Final Proportional value ______
6. Final Integral value ______
7. Final Derivative value ______
8. COMMENTS:

2.5.3 MINIMUM OUTSIDE AIR AND ECONOMIZER CONTROL
1. SDSP controller in Manual mode ______
2. MAT controller in Manual mode ______
3. SDVAF value ______
4. RAT value ______
5. OAT value ______
6. MAT value ______
7. percentOA ______
8. COMMENTS
9. Economizer ON signal ______
10. Economizer ON Light ______

11. Air Damper modulation ____________________
12. COMMENTS

2.5.4 MIXED AIR TEMPERATURE CONTROL
1. MAT controller in AUTO mode ____________________
2. Proportional value ____________________
3. Integral value ____________________
4. Derivative value ____________________
5. COMMENTS

2.5.5 DISCHARGE AIR TEMPERATURE CONTROL
1. DAT controller in AUTO mode ____________________
2. Proportional value ____________________
3. Integral value ____________________
4. Derivative value ____________________
5. COMMENTS

2.6 VAV TERMINAL BOX CHECKS
1. Minimum setpoints ____________________
2. Maximum setpoints ____________________
3. Temperature setpoints ____________________
4. COMMENTS:

2.7 ALARM CONDITION CHECKS

2.7.1 NIGHT THERMOSTAT
1. Space temperature ____________________
2. Night Stat setpoint at activation ____________________
3. Night Stat light status ____________________
4. Fan ON light status ____________________
5. Occupied light status ____________________
6. Supply Fan status ____________________
7. Return Fan status ____________________
8. Exhaust Fan status ____________________
9. Cooling Coil modulation ____________________
10. Outside Air Damper position and modulation ____________________
11. Return Air Damper position and modulation ____________________
12. Relief Air Damper position and modulation ____________________
13. Space Temperature ____________________
14. Night stat setpoint at deactivation ____________________
15. HVAC system status ____________________
16. Final Night Stat setpoint ____________________
17. COMMENTS:

2.7.2 SMOKE ALARM
1. HVAC system status ____________________
2. Fire Alarm status ____________________
3. HVAC system status ____________________
4. Smoke Alarm Light status ____________________
5. Fire Alarm status ____________________
6. Smoke Alarm Light status ____________________

7. HVAC system status ______________________________
8. Panel Reset button pressed ______________________________
9. Smoke Alarm Light status ______________________________
10. HVAC system status ______________________________
11. COMMENTS

2.7.3 HIGH RETURN AIR TEMPERATURE LIMIT ALARM

1. HVAC system status ______________________________
2. High RAT Alarm status ______________________________
3. HVAC system status ______________________________
4. Temperature Alarm Light status ______________________________
5. High RAT Alarm status ______________________________
6. Temperature Alarm Light status ______________________________
7. HVAC system status ______________________________
8. Panel Reset button pressed ______________________________
9. Temperature Alarm Light status ______________________________
10. HVAC system status ______________________________
11. COMMENTS

2.7.4 LOW LIMIT/FREEZE STAT ALARM

1. HVAC system status ______________________________
2. Low Limit Alarm status ______________________________
3. HVAC system status ______________________________
4. Temperature Alarm Light status ______________________________
5. Low Limit Alarm status ______________________________
6. Temperature Alarm Light status ______________________________
7. HVAC system status ______________________________
8. Panel Reset button pressed ______________________________
9. Temperature Alarm Light status ______________________________
10. HVAC system status ______________________________
11. COMMENTS

2.7.5 HIGH DISCHARGE AIR TEMPERATURE LIMIT ALARM

1. HVAC system status ______________________________
2. High DAT Alarm status ______________________________
3. HVAC system status ______________________________
4. Temperature Alarm Light status ______________________________
5. High DAT Alarm status ______________________________
6. Temperature Alarm Light status ______________________________
7. HVAC system status ______________________________
8. Panel Reset button pressed ______________________________
9. Temperature Alarm Light status ______________________________
10. HVAC system status ______________________________
11. COMMENTS

COMMISSIONING REPORT

OUTSIDE-AIR TEMPERATURE-SCHEDULED HYDRONIC-HEATING SYSTEM #1

BROWN HALL, FORT LEONARD WOOD, MO

1 SHUTDOWN CONDITION CHECKS

1.1 SYSTEM INSPECTION

1. Panel Power ______________________
2. Motor HOA Switches ______________________
3. Panel Power ______________________
4. Main Air to Panel (20 psi) ______________________
5. Location of devices correct
   TT12-0203 ______________________
   TT13-0203 ______________________
6. COMMENTS:

7. HTHW (VLV02-0203) position ______________________
8. COMMENTS:

1.2 CONTROLLER CONFIGURATION

1. HWR (CNTL11-0203) configured ______________________
2. HWT (CNTL03-0203) configured ______________________
3. COMMENTS:

2 OPERATING CONDITION CHECKS

2.1 STARTUP CONTROL CHECK

1. CNTL03-0203 manual, 0.0 percent output ______________________
2. HW pump HOA switch position ______________________
3. HW Pump (PUMP01-0203) status ______________________
4. COMMENTS:

2.2 ADJUSTMENTS AND CALIBRATION CHECKS HTHW VALVE CIRCUIT

1. CNTL03-0203 output 0.0 percent,
   IP03-0203 output psi ______________________
2. CNTL03-0203 output 100 percent,
   IP03-0203 output psi ______________________
3. IP03-0203 output 3.5 psi,
   VLV02-0203 position ______________________
4. IP03-0203 14.5 output psi,
   VLV02-0203 position ______________________
5. COMMENTS:

2.3 OUTSIDE AIR TEMPERATURE CIRCUIT

1. OAT controller display ______________________
2. OAT measured ______________________
3. OAT controller display ______________________

4. OAT measured ______________________________
5. COMMENTS

2.4 HOT WATER TEMPERATURE CIRCUIT
1. HWT controller display ______________________________
2. HWT measured ______________________________
3. HWT controller display ______________________________
4. HWT measured ______________________________
5. COMMENTS

2.5 HOT WATER RESET CONTROL CHECK
1. HWR controller in AUTO mode
2. OAT = 50 HWT setpoint = ______________________________
3. OAT = 25 HWT setpoint = ______________________________
4. OAT = 0 HWT setpoint = ______________________________
5. OAT = -10 HWT setpoint = ______________________________
6. COMMENTS:

2.6 HOT WATER TEMPERATURE CONTROL TUNING
1. RFV controller in AUTO mode ______________________________
2. Proportional value ______________________________
3. Integral value ______________________________
4. Derivative value ______________________________
5. COMMENTS:

2.7 OUTSIDE AIR INITIATED SYSTEM SHUTDOWN
1. OAT = ______________________________
2. HW Pump status ______________________________
3. HTHW valve position ______________________________
4. HTHW valve modulation ______________________________
5. COMMENTS:

2.8 MOTOR CONTROL CENTER SHUTDOWN
1. HW Pump HOA position ______________________________
2. HW Pump status ______________________________
3. HTHW valve position ______________________________
4. HTHW valve modulation ______________________________
5. COMMENTS:

APPENDIX C: Performance Verification Test Plans and Procedures

I VARIABLE AIR VOLUME CONTROL WITH RETURN FAN

The purpose of these checks is to verify that the HVAC system performs in accordance with the specified sequence of operation and to verify the accuracy of sensing and controlling equipment.

1 Automatic Operation

Set all of the hand-off-auto (HOA) switches to the AUTO position.

1.1 Occupied, Unoccupied, and Ventilation-Delay Modes of Operation

The set times of the control system's time clock should be temporarily reset so that morning start-up and night-time shutdown of the system can be observed.

_____ 1. When the specified set time for HVAC system start-up has occurred, the delayed vent light should illuminate. Immediately afterwards the occupied and fan-on lights should illuminate, and the supply and return fans should begin to run. The exhaust fan should remain off.

_____ 2. With the system operating, the supply duct static pressure, discharge air temperature, and the return fan flow should come under control within a reasonable period of time without excessive overshoots from the setpoint of the particular process.

_____ 3. When the delayed vent light is illuminated, the outside air dampers should remain completely closed. If an economizer-on indication is present, observe that the outside and relief air dampers remain closed and the return air dampers remain open. If the air temperatures do not allow the economizer to "turn on," simulate return and outside air temperatures so that the economizer will "turn on" and observe that the outside air dampers remain closed.

_____ 4. At the specified set time the delayed vent light should turn off. The air dampers should now be able to modulate. If an economizer-on indication is present, observe that the outside, return and relief air dampers move. If the air temperatures do not allow the economizer to "turn on," simulate return and outside air temperatures so that the economizer will "turn on" and observe that the outside air dampers remain closed. Observe that the exhaust fans will now start.

_____ 5. When the specified set time for HVAC system shut-down has occurred, observe that the occupied and fan on lights turn off and the supply, return and exhaust fans shut down. Observe that the air dampers remain in their normal positions by performing the previously mentioned economizer check. Observe that the cooling coil supply valve remains closed by placing the discharge air temperature controller in manual and adjusting the output. Observe that the supply fan inlet guide vane actuator does not modulate by placing the static pressure controller in manual and adjusting the output. Observe that the return fan inlet guide vane actuator does not modulate by placing the return fan volume controller in manual and adjusting the output. Observe that the air compressor is still operating.

1.2 *Controller and Sensor Calibration*

These checks should be performed with the system in the occupied mode.

_____1. Verify that the actual supply duct static pressure, in the vicinity of the static pressure sensor, is within 0.15 iwc (inches water column) of that displayed of the front of the static pressure controller.

_____2. Verify that the supply duct air volume flow is between 500 and 1500 CFM less than the setpoint (lower display) of the return fan volume controller. (The return air volume flow setpoint is 1,000 CFM less than the supply air volume flow to maintain a positive building pressure.) (Note: The supply duct air volume flow displayed by the return fan volume controller will be 10 times less than the actual flow due to controller configuration limitations.)

_____3. Verify that the return duct air volume flow is within 500 CFM of the process variable (upper display) of the Return fan volume controller. (Note: the return duct air volume flow displayed by the return fan volume controller will be 10 times less than the actual flow due to controller configuration limitations.)

_____4. Verify that the temperature of the discharge air is within 1 °F of the process variable (upper display) of the discharge air temperature controller.

_____5. Verify that the temperature of the return air is within 1 °F of the process variable (upper display) of the economizer controller.

_____6. Verify that the temperature of the outdoor air, in the vicinity of the outdoor air sensor of the economizer, is within 1 °F of the remote setpoint (lower display) of the economizer controller.

_____7. Verify that the temperature of the mixed air is within 1 °F of the process variable (upper display) of the mixed air temperature controller.

1.3 *Minimum Outdoor Air, Economizer and MAT Control*

_____1. Press the min OA test button and observe that the mixed air temperature (upper display) is within 1 °F of the value obtained from the following equation. MAT = %OA * (OAT-RAT) + RAT (Where %OA = 0.10). Perform the test when the OAT is 5 °F or more higher or lower than the RAT, and the supply air flow is low.

Replace the remote setpoint input (outdoor air temperature signal) and the process variable input (return air temperature) to the economizer controller with self-powered current sources to manually set up the conditions necessary to make the following checks.

_____2. Simulate a RAT greater than 75 °F. Simulate an outdoor air temperature (OAT) equal to or greater than the return air temperature, lower the OAT value and verify that when the outdoor air (lower display) is 5 °F lower than the return air temperature (upper display) the economizer ON indicator illuminates and the relief and outdoor air dampers open fully and the return air dampers close completely.

_____3. Increase the OAT and verify that when the outdoor air temperature increases to 3.5 degrees below the return air temperature, the economizer ON indicator turns off and the outdoor air dampers close to their specified minimum position and the return air dampers open.

_____4. Simulate a RAT lower than 70.5 °F. Simulate an outdoor air temperature (OAT) equal to or greater than the return air temperature, lower the OAT value and verify that when the outdoor air (lower display) is 5 °F lower than the return air temperature (upper display) the economizer ON indicator does not illuminate and the relief and outdoor air dampers remain in their minimum OA positions and the return air dampers remain open.

_____5. If the OAT is below 54, observe that the mixed air temperature controller maintains the mixed air temperature to within 0.5 degrees of the displayed setpoint (54 °F). Otherwise, if the economizer is on, and the OAT is 10 °F or more lower than the RAT, change the mixed air temperature setpoint so that it is 2 °F higher than the OAT. Then verify that the mixed air temperature is brought under stable control at the new setpoint within 5 to 10 minutes.

_____6. If neither of the OAT conditions were present for the test in step 5, replace the MAT input signal to the MAT controller with a current source. Ensure that the economizer is "on." Then simulate a MAT below 54 °F and observe that the outside air dampers begin to close and the return air dampers open.

1.4 Discharge Air Temperature Control

_____1. When in the occupied mode, observe that the discharge air temperature controller maintains the discharge air temperature (upper display) to within 0.5 degrees of the setpoint (54 °F)(lower display). Change the discharge air temperature setpoint by 5 °F and verify that the discharge air temperature is brought under stable control at the new setpoint within 5 to 10 minutes.

1.5 Supply Duct Static Pressure Control

_____1. With the supply fan running, observe that the supply duct static pressure controller modulates the supply fan inlet guide vanes to maintain the static pressure (upper display) to within 0.15 iwc of the setpoint (2.5 iwc)(lower display). Change the static pressure setpoint by 0.5 iwc and verify that the static pressure is brought under stable control at the new setpoint within 1 to 5 minutes.

1.6 Return Air Volume Control

_____1. With the supply and return fans running, observe that the return fan volume controller modulates the return fan inlet guide vanes to maintain the return air flow (upper display) to within 500 CFM of the setpoint (lower display) (varies according to the supply air flow). Alter the supply fan flow, by changing the static pressure controller's setpoint, and verify that the return fan flow is brought under stable control at the new setpoint within 5 to 10 minutes.

1.7 Night Stat, High/Low Temperature Alarms, and Smoke Alarms.

_____ 1. With the panel in the unoccupied mode, simulate a contact closure at the night thermostat (place a jumper from pin 95 to 96 on terminal strip 3), observe that the night stat and fan on lights illuminate, and the supply and return fans start and their operation stabilizes within a short period of time. Verify that the air dampers remain in their normal positions. Verify that the cooling coil valve remains closed.

_____ 2. With the fans running, in the occupied mode, simulate a fire/smoke indication by opening the contacts at the fire alarm control panel. Observe that the supply and return fans shut down, the outdoor air dampers close, the fan on light turns off, and the smoke alarm indicator illuminates. Restore the fire alarm contacts to their normal condition, note that the fans do not start and the smoke alarm indicator turns off. Press the control panel reset button and note that the fans turn on.

_____ 3. With the fans running, in the occupied mode, manually open the contacts of the freeze stat (LL02-02), located in the supply duct after the cooling coil. Observe that the supply and return fans shut down, the outdoor air dampers close, the fan ON light turns off, and the temperature alarm indicator illuminates. Restore the temperature alarm contacts to their normal condition, note that the fans do not start and the temperature alarm indicator turns off. Press the control panel reset button and note that the fans turn on.

_____ 4. With the fan running, in the occupied mode, manually open the contacts of the supply duct high temperature sensor (HL03-02). Observe that the supply and return fans shut down, the outdoor air dampers close, the fan ON light turns off, and the temperature alarm indicator illuminates. Restore the temperature alarm contacts to their normal condition, note that the fans do not start and the temperature alarm indicator turns off. Press the control panel reset button and note that the fans turn on.

_____ 5. With the fan running, in the occupied mode, manually open the contacts of the return duct high temperature sensor (HL04-02). Observe that the supply and return fans shut down, the outdoor air dampers close, and the temperature alarm indicator illuminates. Restore the temperature alarm contacts to their normal condition, note that the fans do not start and the temperature alarm indicator turns off. Press the control panel reset button and note that the fans turn on.

2 Hand Position Operation

2.1 Occupied, Unoccupied, and Delayed Ventilation Modes of Operation

_____ 1. With the control panel in the unoccupied and ventilation delay modes, verify that the occupied light is turned off, the delayed vent light is on, and that the supply, return and exhaust fans are off. Place the HOA switch for the supply fan motor starter in the hand position and keep the return and exhaust fans in the AUTO position. Verify that the supply and return fans start, the fan ON light illuminates and the exhaust fans remain off. Observe that the fans come under control within a reasonable amount of time. Verify that the cooling coil valve and mixed air dampers are not under control by placing the DAT and MAT controllers in manual, varying the output signal and observing no movement by the actuators.

_____ 2. Place the panel in the occupied mode and take it out of the delayed ventilation mode, verify that the cooling coil valve is under control by placing the discharge air temperature controller in manual, varying the output signal, and observing movement by the cooling coil valve actuator. Verify that the exhaust fans can now be started and that the air dampers are now under control.

_____ 3. Place the HOA switches of the return and exhaust in the hand position and verify that the fans remain running.

2.2 High/Low Temperature Alarms and Smoke Alarms

_____ 1. With the fans running, in the occupied mode, simulate a fire/smoke indication by opening the contacts at the fire alarm control panel. Observe that the supply and return fans shut down, the outdoor air dampers close, and the smoke alarm indicator illuminates. Restore the fire alarm contacts to their normal condition, note that the fans do not start and the smoke alarm indicator turns off. Press the control panel reset button and note that the fans turn on.

_____ 2. With the fans running, in the occupied mode, manually open the contacts of the freeze stat, located in the supply duct before the cooling coil. Observe that the supply and return fans shut down, the outdoor air dampers close, and the temperature alarm indicator illuminates. Restore the Temperature alarm

contacts to their normal condition, note that the fans do not start and the temperature alarm indicator turns off. Press the control panel reset button and note that the fans turn on.

_____ 3. With the fan running, in the occupied mode, manually open the contacts of the supply duct high temperature sensor. Observe that the supply and return fans shut down, the outdoor air dampers close, and the temperature alarm indicator illuminates. Restore the temperature alarm contacts to their normal condition, note that the fans do not start and the temperature alarm indicator turns off. Press the control panel reset button and note that the fans turn on.

_____ 4. With the fan running, in the occupied mode, manually open the contacts of the return duct high temperature sensor. Observe that the supply and return fans shut down, the outdoor air dampers close, and the temperature alarm indicator illuminates. Restore temperature alarm contacts to their normal condition, note that the fans do not start and the temperature alarm indicator turns off. Press the control panel reset button and note that the fans turn on.

II HOT WATER CONTROL

1 Automatic Operation

Set the hot water pump hand-off-auto (HOA) switch to the AUTO position.

1.1 Occupied, Unoccupied, and Delayed Ventilation Modes of Operation

The set times of the control system's time clock should be temporarily reset so that morning start-up and nighttime shutdown can be observed.

When each of the specified times for shutdown, start-up or delayed ventilation have occurred, verify that the hot water pump remains operating and that the high temperature hot water valve remains under control by setting the hot water controller in manual, adjusting the controller output and observing movement by the hot water valve actuator.

1.2 Controller and Sensor Calibration

_____1. Verify that the actual hot water supply temperature is within 1 degree of the process variable (upper display) of the hot water temperature controller, by comparing its reading to the thermometer in the hot water supply temperature line.

_____2. Verify that the actual outside air temperature, measured in the vicinity of the OAT sensor, is within 1 °F of the process variable (upper display) of the hot water reset controller.

1.3 Hot Water Reset Schedule

_____1. Replace the OAT transmitter input to the hot water reset controller with a self-powered current source. Vary the OAT value and verify that the hot water setpoint, lower display of the hot water temperature controller, varies as shown in the hot water reset schedule shown on the drawings.

_____2. Increase the OAT value above 60 °F, verify that the hot water pump turns off and the HTHW valve closes. Verify that the HTHW valve remains closed by placing the HWT controller in manual, varying the output and observing that the HTHW valve does not move. Decrease the OAT value below

60 °F and verify that the hot water pump turns on and the HTHW valve is now under control of the HWT controller. Replace the OAT transmitter input.

1.4 Hot Water Supply Temperature Control

_____1. Observe that the hot water temperature controller maintains the hot water supply temperature to within 0.5 degrees of the displayed setpoint. Put the hot water reset controller in the manual mode and increase the output so that the HWST setpoint (lower display) of the HWT controller increases by 5 °F. Verify that the hot water supply temperature is brought under stable control at the new setpoint within 5 to 10 minutes. Return the HWR controller to automatic mode.

III HAND AND OFF POSITION OPERATION

_____1. Place the HW pump HOA switch in the hand position. Replace the OAT transmitter input to the hot water reset controller with a self-powered current source. Increase the OAT value above 60 °F. verify that the hot water pump remains running and the HTHW valve remains under control of the HWT controller. Replace the OAT transmitter input.

_____2. Place the hot water pump HOA switch in the Off position, verify that the pump turns off and that the HTHW valve closes.

APPENDIX D: Duct Volumetric Air Flow Balance Study, Kuhn Dental Clinic, Fort Campbell, KY, 2 May 1989

Volumetric Air Flow Rate = sq rt (IWC) * 4005 * duct cross sectional area

ZONE # 1

duct area = 20x18 in. = 2.5 sqft

	IWC			AVERAGE	FLOW	MEASURED	DESIGN
0	0.01	0.04	0.07		(fpm)	CFM	CFM
0	0	0.045	0.1	0.048	875	2189	2420
0	0	0.07	0.1				
0	0	0.18	0.15				

ZONE # 2

duct area = 22x18 in. = 2.75 sqft

	IWC			AVERAGE	FLOW	MEASURED	DESIGN
0.055	0.095	0.075	0.06		(fpm)	CFM	CFM
0.045	0.085	0.065	0.06	0.063	1008.7	2774	2855
0.045	0.075	0.055	0.06				
0.045	0.075	0.055	0.065				

ZONE # 3

duct area = 22x18 in. = 2.75 sqft

	IWC			AVERAGE	FLOW	MEASURED	DESIGN
0.06	0.085	0.09	0.1		(fpm)	CFM	CFM
0.075	0.075	0.075	0.08	0.065	1023.5	2815	3035
0.045	0.05	0.055	0.07				
0.04	0.04	0.04	0.06				

ZONE # 4

duct area = 22x18 in. = 2.75 sqft

	IWC			AVERAGE	FLOW	MEASURED	DESIGN
0.045	0.07	0.07	0.075		(fpm)	CFM	CFM
0.03	0.05	0.05	0.06	0.051	903.9	2485	3130
0.02	0.045	0.045	0.07				
0.035	0.045	0.05	0.055				

ZONE # 5

duct area = 16x8 in. = 0.89 sqft

IWC	AVERAGE	FLOW	MEASURED	DESIGN
0.01		(fpm)	CFM	CFM
0.01	0.01	400.5	356	485
0.01				
0.01				

TOTAL MEASURED AIR VOLUMETRIC FLOW RATE = 10619 cfm

DESIGN AIR VOLUMETRIC FLOW RATE = 11925 cfm

Difference of - 1306 or 11%

ROOM VOLUMETRIC AIR FLOW BALANCE STUDY

ZONE	ROOM	MEASURED FLOW (cfm)	DESIGN FLOW (cfm)	ROOM DAMPER % OPEN
1	EM Lounge	90	165	100
1	SPLY S	200	215	100
1	SPLY N	190	210	100
1	PRTH S	250	600	100
1	PRTH N	190	600	100
1	Exam 2	300	225	100
1	Exam 1	300	225	100
1	Wait 2	170	180	100
1	Total	1690	2420	
2	RM 27	150	230	100
2	RM 28	180	230	100
2	Libry	370	175	100
2	OP 1	220	220	25
2	OP 2	280	220	25
2	OP 3	210	220	25
2	OP 4	200	220	25
2	OP 5	210	220	25
2	OP 6	190	220	25
2	OP 7	210	220	25
2	OP 8	50	220	0.0
2	OP 9	260	220	90
2	OP 10	370	240	100
2	Total	2900	2855	

3	OP 11	260	280	50
3	OP 12	240	260	50
3	OP 13	240	260	50
3	OP 14	250	260	50
3	OP 15	160	260	25
3	OP 16	270	260	50
3	OP 17	260	260	50
3	OP 18	520	260	100
3	HYG 2	130	260	0.0
3	HYG 1	240	260	50
3	PRTH 1	180	265	0.0
3	Total	2750	3035	
4	Wait 1 S	1000	725	100
4	Wait 1 N	500	725	75
4	Admin	300	720	100
4	Office	450	250	10
4	Lbry N	120	250	10
4	Lbry	110	250	10
4	EW Lnge	270	210	50
4	Total	2750	3130	
5	Xray 1	90	185	25
5	Xray 2	150	160	25
5	Xray	200	140	25
5	Total	440	485	

APPENDIX E: Kuhn Dental Clinic–Control System Retrofit Agenda of Training Class

I. SCOPE OF CONTRACT:
PURPOSE: TO INSTRUCT TRAINEE IN THE OVERALL PROJECT SCOPE.
EST. CLASSROOM TIME - 60 MIN.

A. REVIEW OF MULTIZONE SYSTEM
B. REVIEW OF CONVERTER
C. REVIEW OF OLD PNEUMATIC SYSTEM
D. REVIEW OF WHAT CONTROL DEVICES ARE NEW
E. REVIEW OF WHAT CONTROL DEVICES REMAIN

II. REVIEW OF PROJECT DOCUMENTATION:
PURPOSE: TO INSTRUCT TRAINEE IN VALUE AND USE OF PROJECT DOCUMENTATION.
EST. CLASSROOM TIME - 180 MIN (INCLUDING 15 MIN BREAK)

A. OVERVIEW OF JOB DOCUMENTATION
B. OPERATING AND MAINTENANCE MANUALS
   1. SEQUENCE OF OPERATION
   2. CONTROL DIAGRAMS
   3. PANEL MOUNTED DEVICES
   4. REMOTE MOUNTED DEVICES
   5. SPARE PARTS DATA
C. COMMISSIONING PROCEDURES
D. COMMISSIONING REPORT
E. PERFORMANCE VERIFICATION TEST PLAN
F. PERFORMANCE VERIFICATION TEST REPORT
G. TRAINING COURSE DOCUMENTATION
H. QUALIFIED SERVICE ORGANIZATION LIST

LUNCH BREAK - 60 MIN

III. OPERATING SEQUENCE:
PURPOSE: TO INSTRUCT TRAINEE IN PROPER OPERATING SEQUENCE OF CONTROL SYSTEMS.
EST. CLASSROOM TIME - 60 MIN

A. MULTIZONE AIR HANDLING UNIT SEQUENCE
B. CONVERTER CONTROL SEQUENCE

IV. LOCATION AND REVIEW OF REMOTE DEVICES:
PURPOSE: TO SHOW TRAINEE THE LOCATION OF REMOTE DEVICES.
EST. TIME AT SITE - 60 MIN

A. THERMOSTATS
B. VALVES
C. ACTUATORS
D. SENSORS

E. INTERLOCK DEVICES
F. INDICATORS

V. LOCATION AND REVIEW OF PANEL MOUNTED DEVICES:
PURPOSE: TO SHOW TRAINEE COMPONENTS THAT ARE PANEL MOUNTED.
EST. TIME AT SITE - 60 MIN (INCLUDING 15 MIN BREAK).

A. CONTROLLERS
B. TRANSDUCERS
C. PILOT SWITCHES AND LIGHTS
D. ACCESSORY DEVICES

VI. QUESTION AND ANSWER SESSION:
PURPOSE: TO ALLOW TRAINEE FEEDBACK AND QUESTION TIME.
EST. TIME AT SITE - 60 MIN

END OF FIRST TRAINING DAY

VII. DEVICE CALIBRATION AND MAINTENANCE:
PURPOSE: TO INSTRUCT TRAINEE IN PROPER CALIBRATION PROCEDURES AND RECOMMENDED MAINTENANCE.
EST. TIME AT SITE - 90 MIN

A. TRANSDUCERS
B. PILOT POSITIONERS
C. ROOM THERMOSTATS

VIII. CONTROLLER CONFIGURATION AND OPERATION:
PURPOSE: TO INSTRUCT TRAINEE IN PROPER SETUP, TUNING AND OPERATION OF CONTROLLERS.
EST. TIME AT SITE - 300 MIN INCLUDING 15 MIN BREAK AND 60 MIN LUNCH.

A. CONFIGURATION
B. TUNING
C. OPERATION

IX. SPARE PARTS REVIEW
PURPOSE: TO INSTRUCT TRAINEE IN AVAILABLE SPARE PARTS AND REPAIR METHODS.
EST. TIME AT SITE - 30 MIN

X. TROUBLESHOOTING QUESTIONS
PURPOSE: TO QUIZ TRAINEES RESPONSE TO POSSIBLE PROBLEMS.
EST. TIME AT SITE - 60 MIN

COMPLETION OF TRAINING

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